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Boris S. Sokolov

Academician, Russian Academy of Sciences
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Contents

Vol. 4, No. 6, 1996

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State-of-the-Art of the Phanerozoic Isotopic-Geochronologic Scale
A. G. Rublev 525

Biozonal Standards: Calibration Principles, Degree of Sophistication, and Interregional Application (Silurian Graptolites)
T. N. Koren 535

The Midian Stage of the Permian and Its Boundaries
E. Ya. Leven 540

The Paleogene of the Utkholok Peninsula, Western Kamchatka
L. I. Fot'yanova, M. Ya. Serova, F. D. Levin, and N. P. Maslova 552

Regional Angular Unconformities in the Cenozoic Sequences of Kamchatka
M. N. Shapiro, Yu. B. Gladenkov, and A. E. Shantser 567

New Data on the Geology of Iturup Island (Kuril Island Arc)
D. I. Vitukhin, T. V. Oreshkina, Yu. M. Pushcharovskii, and N. V. Tsukanov 580

Stratigraphic Scheme of the Quaternary (Anthropogene) Deposits in Belarus
F. Yu. Velichkevich, A. F. San'ko, T. B. Rylova, V. I. Nazarov†, G. K. Khursevich, and G. I. Litvinyuk 594

Jurassic–Early Cretaceous Landscapes with the Hot Humid Climate in the Northern Arabian Plate
Yu. G. Tsekhovskii 606

Brief Communications

First Discovery of Conodonts from Upper Triassic Deposits of Kotel'nyi Island
T. V. Klets 613

The Pontian-Caspian Region as a Possible Stratoregion of the European Pleistocene
P. V. Fedorov 616

Personalia

Grigorii Yakovlevich Krymgol'ts: On His Ninetieth Birthday
A. I. Zhamoida, E. D. Kalacheva, E. L. Prozorovskaya, V. A. Prozorovskii, K. O. Rostovtsev, and I. I. Sei 622

Chronicle

Fifty Years of Riphean Geology
(All-Russian Conference on General Problems of Stratigraphy and Geological History of the Riphean in Northern Eurasia)
V. A. Koroteev, A. V. Maslov, and M. T. Krupenin 625

Author Index to Volume 4, 1996 628

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 525–534. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 3–13.
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State-of-the-Art of the Phanerozoic Isotopic-Geochronologic Scale

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Abstract—The modern substantiation of the boundaries in the Phanerozoic scale of geologic time is discussed with reference to absolute geochronology. The critical analysis of the isotopic–geochronologic data that form the basis of modern scales shows that only a few of them are suitable for calibration of an adequate scale. At present, reliable dating is available for the following boundaries: the Cambrian lower boundary (535 Ma); the Ordovician–Silurian (440 Ma); the Jurassic–Cretaceous (more than 137 Ma); the Cretaceous–Paleogene (65 Ma); and the Paleogene–Neogene (23 Ma). Moreover, the available data allow determination of many age boundaries in the Ordovician, Late Cretaceous, Paleogene, and Neogene and evaluation of boundary ages between several epochs: the Early–Late Silurian (421 Ma); the Middle–Late Devonian (367 Ma); the Early–Middle Triassic (238 Ma); and the Early–Middle Jurassic (less than 185 Ma). The principles of calibrating the modern scale, in particular the priority of the "geochronologic" approach, are discussed, as also the prospects of future work on the scale and the necessity to elaborate the geologic time scale in this country.

Key words: *isotopic geochronology, chronostratigraphy, geologic time scale, volcanites, the Phanerozoic.*

There is no need to justify the primary importance of an adequate Phanerozoic scale of geologic time for unequivocal correlation between the relative (chronostratigraphic) and the absolute (isotopic) ages of Phanerozoic geologic objects and processes. It should be noted, however, that the quality of the applied scale affects the correctness of the reconstruction of the Phanerozoic history of geologic evolution of separate regions and of the Earth as a whole. Moreover, the correct scale helps to find in this history a place for unstratified (intrusive, ore etc.) bodies, to time the absolute chronology of the main stages in biosphere evolution, to prove the synchronism of sedimentary and magmatic rocks, to afford correct interregional correlations, and to substantiate the serial legends to geological maps. It is also obvious that the adherence to absolute chronology is one of the few tools, if not the only one, for correct correlation of the local and regional stratigraphic scales with the Global Stratigraphic Scale (GSS), when the necessary and sufficient paleontological data are lacking.

The urgency of this problem explains why scientists abroad are persistently searching for perfection of the geochronologic scale in terms of absolute chronology. Despite new data and constant improvement of dating methods, however, none of the existing scales is satisfactory from the point of view of the modern methodology of isotopic–geochronologic research. The present paper is dedicated to the analysis of the current state of the problem and to the ways of its solution.

A few considerations are appropriate before passing to the main part. First, I will not discuss here the scales based on the supposed effect on the Earth's geologic history of its position in the Galactic orbit, which thus correlates the periodicity of geologic events with the time of the Galactic year (Yasamanov, 1993; and others). As I believe, these suppositions are speculative and still insufficiently substantiated, if only due to the ambiguity of the magnitude of the Galactic year. Furthermore, the understanding of this periodicity is based on the existing "normal" scales, the validity of which is far from perfect. Second, I am not a specialist in paleontology and stratigraphy and, therefore, refer the problems of the stratigraphic basis of the geologic time scale (if it is available) to the proper professionals. Third, only the state of the pre-Quaternary Phanerozoic scale is discussed in this paper. The Quaternary formations are dated mainly by applying specific methods that require special discussions by experts. And finally, one remark on terminology. I use the term "geologic time scale" instead of the term "geochronometric scale," recommended in the last issue of the Stratigraphic Code (*Stratigraficheskii ...*, 1992, p. 22) for the "geochronologic scale", the boundaries of which are determined in absolute units. I think it is more natural to call this scale "geochronologic" and to designate the scale implied by the Stratigraphic Code as "chronostratigraphic" or "geohistoric." I am, therefore, using the definition Phanerozoic geologic time scale, PGTS, in this paper to avoid the unsatisfactory term "geochrono-

metric" and the ambiguous "geochronologic." This concept is extensively applied in foreign scientific literature, where it naturally combines two types of scales, the chronostratigraphic and the chronometric (Harland *et al.*, 1982).

THE PRINCIPLES OF APPLICATION OF ISOTOPE GEOCHRONOLOGY IN PGTS CALIBRATION

It is apparent that in calibrating an adequate geologic time scale, we should follow certain rules, the most important of which are as follows: (1) the object selected as a bench mark (reference point) should be exactly correlated with the GSS; (2) the isotopic age of the object should be determined with required precision and unequivocally proved; (3) the isotopic age should correspond rigorously to the geologic age. Leaving the problem of chronostratigraphic allocation out of this discussion, let us review the possibilities of isotopic dating in precise age determination of objects used to compile the PGTS. Otherwise its current state would be difficult to assess.

The limitations of one paper do not allow the elucidation of all problems of acquisition and interpretation of the isotopic–geochronologic data, which has been treated in numerous publications in this country and abroad. Therefore, I present a brief review of the possible system of evidences proving the reality of measured ages, provided that the results of research without adequate proof are to be ruled out for the construction of the scale, although in certain cases they can be employed as "restricting" factors, or for other applied purposes.

The essence of independent isotopic proofs applied to justifying correctness of radiological age determinations is based on a reliably established difference in the geochemical behavior of almost all isotopic–geochronometric systems in natural processes. The systems imply a concrete pair of parent–daughter isotopes in a certain natural geochronometer, e.g., the Rb–Sr system of biotite, or the Sm–Nd system of the whole rock. This means that in the absence of distorting factors, all methods applied in isotope geochronology for the whole rock (bulk samples), or its mineral components, will determine identical time corresponding to the age of the object. In practice, the reverse statement is also true: the coincidence of measured ages for all isotopic–geochronometric systems implies the absence or insufficient intensity of distorting factors, and definitely proves the correctness of the age obtained for the object being studied.

The global experience of geochronology shows that obtaining the necessary proofs does not require the use of all the methods for all rocks and minerals composing the object being studied. In most cases, it is enough to apply two or three methods to a restricted number of natural geochronometers; in favorable conditions, one method will suffice to obtain the necessary proofs. To achieve that, the methodologically correct application of each method is necessary in order to use criteria of authenticity that are inherent to any of them and based on the regularities of geochemical behaviors of isotopes in corresponding systems. Further elucidation of these problems can be obtained from special publications (Pushkarev *et al.*, 1978; Shanin *et al.*, 1979; Rublev, 1984; and others). Avoiding a number of methodological problems and proofs, I shall briefly formulate these criteria as applied to each method.

In the U–Pb method, when zircon is the most frequently used mineral for geochronological research, the basic criterion of authenticity is the coincidence of the measured ages calculated by three isotope ratios: $^{206}Pb/^{238}U$, $^{207}Pb/^{235}U$, and $^{207}Pb/^{206}Pb$, i.e., the internal concordance. If the zircon data are discordant, then a series of samples of one generation is used to plot the discordia on the Ahrens–Weserill coordinates. The upper intersection of the isochron with the concordia shows the time of formation of the studied zircon generation. The greatest disadvantage in the U–Pb method is the presence of xenogenic components in zircons, and then they are discordant. The formation time of these zircons is determined by the lower intersection of discordia with concordia if the former can be derived. Consequently, a single dating by one ratio cannot be regarded as reliable without an analysis of all analytical data. To a still higher degree, the data of the alpha-lead and fission-track methods used earlier cannot be applied here.

The Rb–Sr and Sm–Nd methods are used for separate minerals and for rocks, in the latter case, invariably in the isochron variant. The necessary condition for correct results is the correspondence of the studied series of samples to the isochron model, which is determined by the value of the mean square weighted deviation (MSWD) of the order of a unit. The criterion of reliability is the obligatory coincidence of ages of different minerals with the isochron age, i.e., the distribution of data points corresponding to the minerals on the isochron for the whole rock sample. In certain cases, the coincidence of the measured ages of different minerals is sufficient, and the rock samples may not be involved. Any single dating by minerals, the monomineral isochrons, or isochrons by the whole rock samples cannot be regarded as reliable, if the age is determined only from these results. This statement does not mean that the isochrons are necessarily misrepresenting, however, in such cases they lack reliable proof that the system has never been disturbed.

When the K–Ar method is applied, the main criterion of data reliability is the coincidence of the measured ages of different minerals from the rock sample, which are clearly different in their ability to lose the radiogenic argon. At mild discordance, if the measured ages correspond to a series of minerals variably resistant to the loss of argon (in declining order: amphibole

/pyroxene/—muskovite—biotite—feldspar—glauconite), then an analysis of minerals from a series of samples is required to find regularities in the variation of differences in age measurements and to reveal the minerals, the K–Ar system of which remained intact under external effect. The greatest risk (albeit rare) in K–Ar dating, but is the excess, of argon of various origin in almost all minerals except muskovite. Therefore, the analysis of whole rock samples only, or minerals with low stability to the argon loss (feldspars, glauconites), can produce at best only information about the upper age limit of the formation time of the object.

Authors abroad often use data from the age spectra method ($^{40}Ar/^{39}Ar$). We should be careful in trusting these data, because they can be assumed as undistorted only if the plateau ages of different minerals coincide. In this case, the plateau itself should correspond to 70–90% of the extracted argon in total. This remark does not concern biotites, which can display the plateau regardless of the loss or capture of argon.

If in the course of geochronologic study a certain method fails to produce the required proofs of the actuality of the measured age, it is necessary to apply at least one other method according to the mineral–geochemical peculiarities of the object being studied. Moreover, since we do not know *a priori* the number and intensity of natural factors distorting the isotopic systems, it is necessary to employ at least two isotopic-geochronologic methods for dating the reference objects.

Now I consider the possibilities for reliable age determination of different rock types generally used to compile the current PGTS also in view of the geologic significance of the isotope age.

Intrusive rocks, except ultrabasic, are preferable for isotope datings, because they can be treated by all isotopic–geochronologic methods, and the maximal number of natural geochronometers can be applied to them. As shown by the world geochronologic experience, the methodologically correct isotopic methods of study of petrographically unaltered Phanerozoic intrusive rocks produce reliable datings in the absolute majority of cases. It is considerably more difficult to determine the age of intrusions greatly altered by secondary processes and rocks of complicated genesis lacking the stage of isotope homogenization in the magmatic melt.

Though the intrusive rocks are preferable for isotopic dating, they are hardly suitable as markers for the scale. The intrusive rocks seldom have accurate enough chronostratigraphic allocation. In most cases, we are able to determine only their upper or lower age boundary, and the age interval between the moment of intrusion emplacement and one of these boundaries is often too long (no less than several million years) to pose the boundary in the scale. Furthermore, the geologic age of intrusions corresponds to the time of magma intrusion, whereas the isotopic chronometers fix a certain moment in rock evolution, when magma has already crystallized and the temperature has dropped to the level, at which the corresponding isotopic–geochronologic systems close up. There is evidence that the indicated interval in the life of meso- and hypabyssal intrusive bodies can be no more than a few million years (Rublev, 1986), but the summary effect of these two factors make intrusive bodies practically unsuitable for chronostratigraphic markers.

Volcanic rocks can be dated with more difficulties than intrusives owing to two main causes. The first is the low degree of crystallization of volcanic rocks which makes extracting the necessary minerals of requisite quantity and purity difficult. However, with the improvement of the analytical technique, the effect of this factor decreases. The second cause is the frequent alteration of volcanic rock up to complete secondary transformation of the mineral-geochronometers. In such cases the sampling of the necessary rock material is arduous. If it is achieved, then the age determination of the volcanic rocks is almost identical to that of the intrusives, though with certain specific aspects (Bibikova, 1985; Gorokhov, 1985; Morozova *et al.*, 1985). Moreover, the K–Ar and Rb–Sr methods are mainly used when dating volcanic rocks, because the application of the U–Pb method is hindered by the difficulty of zircon extraction.

For more precise specification of the geologic time scale, the volcanic rocks as markers are indubitably superior to all other types of rocks according to such properties as geologically "instantaneous" formation, which makes their "isotopic" and "geologic" ages identical. However, volcanic rocks are prone to cause difficulties in rigorous chronostratigraphic allocations. In fact, the most suitable rocks for isotope dating are those of acid and intermediate composition typical of continental environments. Naturally, the stratigraphic allocation of marine volcanites is more precise and reliable, but the majority of them are basaltoids, the most difficult rocks for isotopic dating. Progress in basaltoid age determinations, I believe, can be made with the Sm–Nd method, provided the accuracy of determination of Nd-isotope composition is improved.

Phanerozoic sedimentary rocks, the natural markers for the stratigraphic scale, cannot be reliably dated with modern techniques of isotopic geochronology. Only the minerals of the glauconite group (MGG) and illites or mixed-layer illite–smektites can be used as "geochronometers," whereas isochron dating of the whole rock samples is pointless for many reasons. The MGG are characterized by a rather low stability against the thermal losses of argon that can become actually perceptible above 50°C with due regard to the real duration of geologic processes (Aprub and Levskii, 1976); i.e., already at the depths of about 2–3 km. Besides, unlike other minerals, except biotites, the MGG have nearly identical stability of K–Ar and Rb–Sr systems, which precludes the application of such reliability criterion as coincidence of ages obtained with different methods.

Therefore, an age value obtained for glauconite, even if this mineral is perfect by all mineralogical and geochemical parameters (Odin, 1982a), is valid for application only as the upper age limit for that rock. Strictly speaking, even this is not always true, because several researchers suggest the possible inclusion of redeposited older glauconite in sedimentary rocks.

Illites as geochronometers are, no doubt, more reliable. According to the published data, their K–Ar and Rb–Sr systems have different stability against external impacts and, therefore, the coincidence of K–Ar and Rb–Sr ages for illites from unmetamorphosed sedimentary rocks is, apparently, the most precise determination of their time of formation, provided they are represented by one generation. The latter hardly ever occurs. Most frequently, the illite in sedimentary rocks is a mixture of two or three generations, and their separation into pure monogenetic components is extremely complicated and laborious (Gorokhov *et al.*, 1994). The main drawback of illite as a sedimentary geochronometer, however, is that it is formed not during deposition, but in the course of diagenesis of sediments and (or) their epigenetic transformation. This means that without the determination of the time interval between the indicated processes, which is hardly the same in different geologic situations, the dating of illites can likewise be used only as the upper age limit of the host rock. This is also true, to a certain extent, of the MGG, though there are data about their possible formation at the early stages of sediment lithification.

The improvement of analytical procedures enables an increasing amount of data on bentonites and volcanic ashes to be used for PGTS elaboration. On the one hand, these rocks contain materials from volcanic eruptions, including minerals traditionally used for isotopic dating (biotite, sanidine, zircon). On the other hand, these rocks can often be fixed with precision to the GSS. The main difficulties in handling these rocks are the small amounts of the necessary minerals, their alteration and possible xenogenic contamination (Baadsgaard and Lerbekmo, 1982). If these obstacles are overcome, then the dating of bentonites and volcanic ashes differs from the datings of magmatic rocks only by the impossibility of using isochron methods for the whole rock, which is, by the way, not always necessary.

THE PRESENT STATE OF GEOCHRONOLOGIC SUBSTANTIATION OF THE EXISTING PGTS

Proceeding from the above, I would emphasize two aspects that should be taken into account when estimating the validity of any scale. (1) For different reasons, the intrusive and sedimentary rocks (except bentonites and volcanic ashes) should not be used at present for the construction of an adequate PGTS. The results on these rocks, even with correct application of the isotopic–geochronologic methods, can determine only the age restrictions (most often the upper age limit) for the scale unit boundaries. (2) The determinations cannot be regarded as reliable if they are made, irrespective of the method, only for the whole rock samples; for glauconites and biotites with K–Ar and (or) Rb–Sr methods; for any individual mineral, except zircon, with one method; or by $^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ratios, if they are the only substantiation of the age.

With this in mind, let us discuss the isotopic–geochronologic data now used in the calibration of the most popular PGTS. We will begin with the analysis of the data for the scale of the London Geological Society (Harland *et al.*, 1964), because many of them were incorporated into all other later scales. Its calibration was based on the dating results of 337 objects traditionally designated in scientific literature as PTS 1–337. They were later amplified by data for 29 other objects designated as PTSS 338–366 (Harland *et al.*, 1971). If we exclude from these data those, to which the restrictions mentioned above are applicable, and those obtained from altered samples and rejected by the authors of the scale due to the inaccuracy of chronostratigraphic allocation, then the results on only 15 objects will remain suitable for the PGTS construction. Three of these objects belong to the Miocene (PTS 262–264; 266–269, and 275), one to the Eocene–Oligocene boundary (PTS 300), one to the Paleocene (PTSS 362), one to the Cretaceous–Paleogene boundary (PTS 199), and six objects to the Late Cretaceous (PTS 201, 202, 204 and PTSS 363, 364, 365). One more object belongs to the Devonian (PTSS 354), and two others to the Ordovician (PTS 156, 157). Therefore, these data are obviously insufficient for compilation of a proper scale.

In 1982, Harland and his co-authors, recognizing the weak points of the scale, the availability of new data, and the need to recalculate numerical values of boundaries in accordance with new constant rates of radioactive decay (Steiger and Jager, 1977), suggested a new variant of the PGTS (Harland *et al.*, 1982), which nonetheless preserves the bulk of the results for the scale of 1964. When R.L. Armstrong discredited several datings with the addition of his own data, presented at the symposium on the scale at the 25th International Geological Congress, and when other results on new objects were reported by other participants (Cohee *et al.*, 1978), the isotopic–geochronological basis of the new scale was not appreciably improved, because most of the materials of the Sydney Symposium do not meet all aforementioned restrictions.

As a result of work on the International Geological Correlation Program (Project 133), G.S. Odin published, also in 1982, another well-known variant of the PGTS (Odin, 1982b). It was based on age determinations of 251 objects. Since the data were presented in the monograph: *Numerical Dating in Stratigraphy* (1982), their traditional abbreviation is NDS. In this case, the age determinations were obtained for 135 glauconites, 24 whole rock samples were dated by the K–Ar method, 21 by the Rb–Sr method, etc. As a

result, only seven objects can be considered to be reliably dated; three of them belong to the Cretaceous (NDS 105, 111, 127), two to the Early Jurassic (NDS 183, 184), one to the Ordovician (NDS 129 = PTS 156), and one to the Early Miocene (NDS 155). With certain restrictions, the data are usable for seven other objects (NDS 103, 104, 106, 107, 118, 157, 218). All of them were obtained by the K–Ar method from unaltered biotites in bentonites and correspond to the Late Cretaceous. As shown in practice, these datings are seldom distorted, but even their application insufficiently substantiates the suggested scale.

The principal difference between the two scales of 1982 is in the age determination of the Cambrian lower boundary. Odin estimated it to be 530 Ma old, while Harland and co-authors suggested the level of 590 Ma. The data for the Cretaceous lower boundary differed by 14 Ma (130 and 144 Ma, respectively), and by 20 Ma (418 and 438 Ma) for the Silurian lower boundary. Other disparities are not substantial, but for reasons discussed above this does not imply that the accepted age values are correct.

In 1982, at the Seminar *"Geochronology and Geological Record"* in London, a comprehensive discussion of the PGTS focused on several problems: the high diversity of available scales, the discrepancy in the principles of their calibration, new results including those obtained at an updated level of research on former objects, and improvement of the stratigraphic basis. Proceedings of the seminar were published later (*The Chronology* ..., 1985), and from their data and discussion results Snelling (1985) suggested another well-accepted PGTS variant, actually the compilation of the 1982 scales. Few of the new result, debated at the seminar, merit consideration, primarily those on the Late Devonian (Frasnian) volcanites of the Cerberean Caulderon Formation 367 Ma old (Williams *et al.*, 1982) (NDS 234) and the Ludlovian volcanites of the Laidlow Formation 421 Ma old (Wyborn *et al.*, 1982). The absolute majority of other data was either on intrusive rocks, or unreliable.

The American scale of 1983 (Palmer, 1983), frequently mentioned in the literature, is a pure compilation of the 1982 scales mentioned above and the data of the London seminar. Essentially the same is the latest scale by Harland and co-authors (Harland *et al.*, 1990). It will suffice to mention that among 670 isotopic ages for the Phanerozoic part of the scale, 163 are derived from the first work of the authors (Harland *et al.*, 1964) and 278 from the scale of 1982 by Odin.

The situation with reference dating of objects with stratigraphically reliable allocations has been improving lately owing to a more extensive application of bentonites and volcanic ashes as indicators. A typical example is the studies carried out during many years by H. Baadsgaard, J. Lerbekmo and their co-authors of the Cretaceous–Paleogene (65 Ma) and Campanian–Maastrichtian (73 Ma) boundaries. The research was accomplished with combined isotope–geochronological methods of study on bentonites in Canada (Badsgaard *et al.*, 1988, 1993).

No less impressive are the results obtained with the U–Pb method on zircons from the interbeds of volcanic ashes in the Ordovician and Lower Silurian stratotypes of Britain. The sufficiently concordant age values in all isotopic aspects allowed the highly reliable determination of the Ordovician–Silurian boundary age at about 440 Ma and that of the Llanvirnian and Llandeilian ages at 464 Ma (Tucker *et al.*, 1990).

Equally reliable geochronologically, but less definite chronostratigraphically, the data for the Ordovician rhyolites from the Buchans and Robert Arm formations in Canada suggest that the lower boundary of the Llanvirnian Stage is 473 Ma old (Dunning *et al.*, 1987; Dunning and Krogh, 1991).

Very important and geochronologically reliable results were obtained for zircons from the Lower Cambrian ashy tuffs in the lower reaches of the Lena River (Bowring *et al.*, 1993). According to this data, the lower boundary of the Cambrian, which Russian geologists place at the base of the Tommotian Stage, is 535 Ma. The Resolutions of the International Stratigraphic Commission state that the lower boundary of the Cambrian lies at the base of the *Phycodes pedum* Zone (Landing, 1994) and, therefore, the lowermost Cambrian should include the pre-Tommotian Nemakit–Daldyn Stage. In this case, the age of the Cambrian–Precambrian boundary is 545 Ma. In any event, the age of the Cambrian lower boundary should be much younger than 560–570 Ma as was generally assumed.

As confirmation of the results on NDS 183 and 184 for the Pliensbachian–Toarcian (Early Jurasic) subvolcanic rocks of the northern Caucasus, a quite reliable age value in the 180–190 Ma interval was obtained by the $^{40}Ar/^{39}Ar$ method for biotites and plagioclases (Hess *et al.*, 1987).

The sufficiently adequate U–Pb dating of zircons from the tuff interbeds in California imply that the Jurassic–Cretaceous boundary is somewhat older than 137 Ma, whereas the Berriasian–Valanginian boundary is about 135 Ma old (Bralower *et al.*, 1990).

Many publications have been recently dedicated to the different methods of age determination of the Eocene–Oligocene boundary by using the products of volcanic eruptions in northern Italy, and the generalized results indicate that it corresponds to the 33–37 Ma interval (Odin *et al.*, 1991).

All these results were incorporated by Odin in the recently published PGTS (Odin, 1994). But the new variant differs only slightly from the 1982 scale, that is acknowledged by the author. And no wonder, since the new scale retains the earlier data on 251 objects from the 1982 scale, and the larger part of the 150 new age determinations does not comply with the necessary requirements. This observation also refers to such seemingly reliable data as those cited in the works by

Claoue-Long and co-authors on age determination of the Permian–Triassic (251.2 ± 3.4 Ma) and Devonian–Carboniferous (353.4 ± 4.0 Ma) boundaries with the U–Pb method on zircons from bentonites (Claoue-Long *et al.*, 1991, 1992). Two circumstances, caused by the fact that the analytical results were obtained with the ion mass spectrometer SRIMP, prevent the acceptance of the results for the reference points of the scale.

First, though the application of the SRIMP technique implies a large number of individual determinations, their values are obtained with considerable defects. The authors carried out a specific mathematical processing of the results, which though reduced the final error, but still produced a real error value at least 5–10 times greater than the indicated one. Second, the most serious errors in this technique are associated with the measurements of $^{207}Pb/^{235}U$ ratio, and precludes the accurate determination of the position of data points on the diagram with concordia, in other words, the evaluation of possible losses of radiogenic lead or the presence of xenogenic component. The authors, practically *a priori*, have to assume the absence of such phenomena, and this likewise discredits the presented results as scale markers. By the way, insufficient accuracy also prevents acceptance of the age determination of the Permian–Triassic boundary at 249 ± 15 (1σ) Ma obtained by Rb–Sr method on whole rock samples and minerals from basalts of the Polar Urals (Andreichev, 1992).

The latest materials on the PGTS known to the author were presented at the Eighth International Conference on Geochronology, Cosmochronology and Isotope Geology in June 1994 in Berkeley. The major part of the materials, satisfying the requirements of scale construction, were on the Neogene and Paleogene (Montanari and Swisher, 1994; Montanari *et al.*, 1994; Deino *et al.*, 1994). The results were obtained mainly by using different modifications of K–Ar age determination of volcanic rocks and ashes from the Cenozoic sections in Italy. They permit the establishment of reliable age boundaries for several epochs and ages of the indicated periods. Interesting results were also presented on the age determination of the lower boundary of the Middle Triassic by U–Pb method applied to zircon grains from the interbeds of volcanic tuffs in the southern Alps (Mundil *et al.*, 1994). Though the paper presents the age values calculated only by $^{206}Pb/^{238}U$ ratio, they allow the reliable age of the boundary to be no less than 238 Ma when combined with $^{40}Ar/^{39}Ar$ data on feldspars for NDS 196.

Consequently, if the stratigraphic position of the enumerated objects is correct, then the isotopic–geochronologic justification of PGTS at the beginning of the second half of 1994 is as follows. The Tommotian Age starts at 535 Ma (Bowring *et al.*, 1993), or even earlier (Isachsen *et al.*, 1994), but there are no reliable data on the Ordovician stages before the Llanvirnian. Apparently, the age of the Llanvirnian lower boundary is quite different from 473 Ma (Dunning *et al.*, 1987; Dunning and Krogh, 1991). The Llanvirnian–Llandeilian boundary is 464 Ma old, whereas the boundary ages of the following Ordovician stages can be identified by interpolation in a rather short age interval. The age of the Ordovician–Silurian boundary slightly differs from 440 Ma (Tucker *et al.*, 1990) as it follows from data for NDS 129, PTS 156, and PTS 157. The base of the Ludlovian (Early–Late Silurian boundary) is somewhat older than 421 Ma (Wyborn *et al.*, 1982), but from there until the early Frasnian, or 367 Ma (Williams *et al.*, 1982), reliable age determinations are lacking. The Devonian–Carbonineferous, Carboniferous–Permian, Permian–Triassic, and Triassic–Jurassic boundaries are inexactly dated. Only some intervals can be suggested on the basis of age determinations of intrusions protruding them. The age of the Early–Middle Triassic boundary is also estimated to be 238 Ma (NDS 196) with sufficient reliability (Mundil *et al.*, 1994). In the Lower Jurassic, near the Pliensbachian–Toarcian boundary, two marker objects (NDS 183, 184) are dated as about 185 Ma old, but with a serious analytical error of no less than 10 Ma. A similar dating of this boundary is confirmed by the data in the paper by Hess *et al.* (1987). The next marker, the Berriasian bentonites, is 137 Ma old (Bralower *et al.*, 1990), and further until the Early–Late Cretaceous boundary there are no reliable age determinations of stratigraphically well-allocated objects.

The remaining part of the scale, from the beginning of the Late Cretaceous to the Quaternary, can now be considered justified even up to the boundary ages of almost all the stages. At least, the few discrepancies between different sources do not exceed 1–3 Ma, and that owing to analytical errors or inaccuracy in stratigraphic allocations. To sum up the results on this part of the scale, I would note only the boundary ages between epochs; i.e., between Early and Late Cretaceous (97 Ma), Late Cretaceous and Paleocene (65 Ma), Paleocene and Eocene (53 Ma), Eocene and Oligocene (34 Ma), Oligocene and Miocene (23 Ma), Miocene and Pliocene (5.3 Ma). More details can be derived on this part of the scale from a paper by Odin (1994). The age of the Quaternary lower boundary requires a more precise definition within the interval of 1.5–2.5 Ma.

The results presented above represent the entire data set derived from available publications. No doubt, part of the data, particularly the most recent, is probably omitted due to restricted access to foreign publications nowadays. But the missing information can hardly make essential changes in the represented situation. Obviously, the adequate PGTS is at present fragmentary and requires further study. In this context, I discuss certain problems and questions below.

DISCUSSION

One of the main problems is the elucidation of the main principles of the PGTS calibration. Odin

distinguishes three approaches: statistical, graphic, and geochronological (Odin, 1994). Like Odin, I certainly belong to the supporters of the priority of the geochronologic approach and, therefore, do not present my own variant of the scale in the traditional sense. I completely agree with Odin's comments on the statistical and graphic (interpolation) approaches along with the main points of the mentioned paper, to which I add the following remarks.

The interpolation method for regular division of any time interval between sufficiently remote reference points of the PGTS into a number of basic units (ages or stages, after Odin) of this interval should not be applied because of the different duration of the stages even within one period. If we take the PGTS subdivisions adopted in this country (*Stratigraficheskii* ..., 1992), and the stage durations, which are often approximate and derived from the existing scales, we shall see that there are short stages of 1–5 Ma (Piacenzian, Coniacian, Anisian, Llandeilian) and much longer ones of 10–20 Ma (Campanian, Albian, Visean, etc.). It is, therefore, obvious that the application of the interpolation method (e.g., Harland *et al.*, 1982, 1990) can be excused by the lack of a sufficient number of reference points and the necessity to use in practice any PGTS more or less approximating the real one. This method has nothing in common with the proper way to construct an adequate scale. This statement does not mean that the interpolation approach is inapplicable for that purpose in general. It can and should be used, but only for placing the stage boundaries, if we have reliably dated objects in the neighbouring stages, while the boundary age itself is undetermined.

Just one remark about the statistical method: no amount of statistical processing of unreliable age measurements can improve their authenticity. This method reveals the most frequent value, but its reference to the real age can be known only after correct dating of the corresponding boundary. Likewise, there is no point in statistical processing of the age values for unit boundaries accepted in different scales, as done by Afanas'ev (1987, 1993) in his publications. The basic approaches of this author merit special critical analysis. I shall mention here two items.

First, Afanas'ev rejects some boundary values using such criterion as occurrence frequency, but not the rate of geochronological reliability. Consequently, it is apparent that this approach will result in the loss of reliable determinations, because they are in the minority. For example, the lower boundary of the Tommotian Stage was dated as 530 Ma old only in Odin's scale of 1982, while in other scales the pertinent value varies from 560 to 600 Ma. Naturally, Afanas'ev rejected it, although the most realistic value of the boundary today is 535 Ma.

Any statistical processing of a series of values will, of course, result in a more precise average, if the most outstanding figures are rejected. There is yet another aspect of Afanas'ev's approach. His data sorting suggests that boundary ages measured with minimal errors are to be included into the sample. This means that all of Afanas'ev's scales, except the first one, will incorporate all their previous variants with the accuracy of the calculated boundary ages artificially increasing with time. If prolonged, this process may result in zero error in the age determinations of boundaries, but the sample will finally contain only Afanas'ev's own artificial scales. It seems apparent that such values may have only accidental coincidences with the actual age of the unit boundaries.

The criticism of the modern statistical method and interpolation approach does not entirely exclude their application. The former method can be used, if a large number of reference age determinations is available for a certain limited chronostratigraphic interval (less than an age). In this case, the statistical method will either improve the accepted value (if all age values in the sample do not differ within the analytical error), or reveal the inaccuracies in the chronostratigraphic allocation of objects or the "age" slip (provided the range of age determinations considerably exceeds the analytical error). In fact, we still have to wait for a real opportunity to apply the statistical method to most of the boundaries.

The essence of the "geochronological" principle of the PGTS calibration is given in the three items of the first part of the paper, and it must be strictly satisfied, I think, particularly with regard to the isotopic–geochronological data. This rule is important not only for the correct solution of the problem and as a way to avoid ambiguous results. The strict requirements are justified by the greater possibilities of modern isotope geochronology, such as (1) greater precision of age measurements, which in favorable situations approaches 1–2 Ma for the Paleozoic and Mesozoic and less than 1 Ma for the Cenozoic; (2) the greater sensitivity of the isotope analysis that allows the use, in the best laboratories, of extremely small amounts of minerals; (3) current progress in the understanding of how the real, true age of objects could and should be obtained (and proved). Moreover, I think that only the application of precise and reliable ages of stratified formations can help resolve debated problems in stratigraphy, including those related to the PGTS calibration.

The "geochronological" approach to the PGTS calibration prescribes the character of future work with the scale. I believe that there are now two mutually complementary ways of calibrating an adequate scale. The first is to conduct further paleontological research elucidating the precise chronostratigraphic position of those objects that have reliable isotope–geochronologic age substantiation, but insufficiently strict allocation in the GSS. The second and main course is to select new reference objects, the age determination of which would help solve the problem, to reliably date them, and also

to study further the geochronology of the objects, the results of which are still unreliable.

The realization of both courses in the calibration of the scale or its separate parts should be carried out by coordinated and consistent efforts of stratigraphers, paleontologists, and geochronologists within combined programs. To obtain the universal PGTS, the programs should be international. This does not exclude, but rather implies realization of regional (national) programs of calibrating corresponding scales. The latter are necessary not only because they are parts of the general scale, as likewise postulated by Odin (1994) in regard to the GSS. The regional or national PGTS are required for geological mapping and compilation of legends, because in most cases it is rather complicated to carry out a direct correlation of the local and regional stratigraphic units with the Global Stratotype Sections and Points (GSSP). Furthermore, calibration of the regional (national) PGTS will contribute to the progress in the realization of the GSSP concept, because now, by Odin's data (Odin, 1994), only 18 boundaries of the main GSS units are determined in accordance with the requirements of this concept.

Besides general requirements, the selection of boundary stratotypes of the GSS units should comply with the possibility of dating the boundary by isotopic geochronology. This means that in the actual vicinity of the boundary, or on both sides of it, there should be objects, the ages of which can be determined with isotopic methods (volcanites, bentonites, etc.). The satisfaction of these requirements will encourage both the PGTS calibration and correlation of any local and regional stratigraphic units with the GSS, if they contain rocks, the isotope age of which can be determined, whereas paleontological data do not ensure the uniqueness of this correlation.

I consider the creation of the national, Russian PGTS extremely urgent and important. Beyond purely scientific purposes, it will help to realize the compilation of a new generation of the State Geological Map (SGM) of Russia in scales 1 : 200 000 and 1 : 1 000 000. Without the PGTS, adopted as an obligatory document, it is difficult to unify legends, particularly for magmatic rocks, and to effectively apply numerous reliable isotope dating for improvement and greater informative capacity of the new SGM generation. Moreover, it should be taken into account that at present only a few objects in Russia are dated as reference points for the scale of this country.

The possibility of calibrating the national scale is provided primarily by numerous volcanogenic formations on the territory of Russia, which are different in age and have sufficiently reliable chronostratigraphic allocations. As far as I am aware, these are the Cambrian and Devonian volcanites in the Altai–Sayan area, the Silurian and Permian volcanic rocks of the Urals, the Permian–Triassic volcanites in the north of the Siberian platform, the Mesozoic–Cenozoic formations of the Far East, Northeastern and Transbaikalia regions. By improving analytical capacities of our laboratories, the list of reference objects can be amplified by using bentonites. The advantages of international cooperation should likewise be applied for the benefit of this research.

I sincerely hope that the problems described in this paper will draw the attention of the geological community to this field of study, which was practically neglected in Russia for the last twenty years.

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Reviewer E.V. Bibikova

REFERENCES

Afanas'ev, S.L., *Geokhronologicheskaya shkala fanerozoya i problema geologicheskogo vremeni* (The Phanerozoic Geochronological Scale and the Problem of Geologic Time), Moscow: Nedra, 1987.

Afanas'ev, S.L., The Isotopic-Geochronological Scale of the Vendian–Phanerozoic, *Geol. Geofiz.*, 1993, vol. 34, no. 3, pp. 3–9.

Andreichev, V.L., The Rubidium–Strontium Age of Basalts from the Polar Urals, *Dokl. Ross. Akad. Nauk*, 1994, vol. 326, no. 1, pp. 139–142.

Aprub, S.V. and Levskii, L.K., The Study of the Radiogenic Argon Retention in Glauconites, *Geokhimiya*, 1976, no. 1, pp. 103–108.

Baadsgaard, H. and Lerbekmo, J.F., The Dating of Bentonite Beds, *Numerical Dating in Stratigraphy*, Odin, G.S., Ed., Chichester: Wiley, 1982, pp. 423–440.

Baadsgaard, H., Lerbekmo, J.F., and McDougall, I., A Radiometric Age for the Cretaceous–Tertiary Boundary Upon K–Ar, Rb–Sr, and U–Pb Ages of Bentonites from Alberta, Saskatchewan, and Montana, *Can. J. Earth Sci.*, 1988, vol. 25, no. 7, pp. 1088–1097.

Baadsgaard, H., Lerbekmo, J.F., Wijbrans, J.R., *et al.*, Multimethod Radiometric Age for a Bentonite Near the Top of the *Baculites reesidei* Zone of Southwestern Saskatchewan (Campanian–Maastrichtian Boundary), *Can. J. Earth Sci.*, 1993, vol. 30, no. 4, pp. 769–775.

Bibikova, E.V., The Uranium–Lead System in Volcanic Rocks, in *Izotopnoe datirovanie protsessov vulkanizma i osadkoobrazovaniya* (The Isotopic Dating of Volcanic and Sedimentation Processes), Moscow: Nauka, 1985, pp. 3–18.

Bowring, S.A., Grotzinger, J.P., Isachsen, C.E., *et al.*, Calibrated Rates of Early Cambrian Evolution, *Science*, 1993, vol. 261, pp. 1293–1298.

Bralower, T.J., Ludwig, K.R., Obradovich, Jones, D.L., Berriasian (Early Cretaceous) Radiometric Ages from the Grind-

stone Creek Section, Sacramento Valley, California, *Earth Planet. Sci. Lett.*, 1990, vol. 98, no. 1, pp. 62–73.

Claoue-Long, J.C., Jonnes, P.J., Roberts, J., and Maxwell, S., The Numerical Age of the Devonian–Carboniferous Boundary, *Geol. Mag.*, 1992, vol. 129, no. 3, pp. 281–291.

Claoue-Long, J.C., Zang, Z., Ma, G., and Du, S., The Age of the Permian–Triassic Boundary, *Earth Planet. Sci. Lett.*, 1991, vol. 105, no. 1/3, pp. 182–190.

Contributions to the Geologic Time Scale, Papers given at the Geological Time Scale Symposium 106.6, 25 IGC, Sydney, Australia, August 1976, Cohee, G.V., Glaessner, M.F., and Hedberg, H.D., Eds., Tusla: Amer. Ass. Petr. Geol., 1978, no. 6.

Deino, A., Montanari, A., Coccioni, R., and Odin, G.S., $^{40}Ar/^{39}Ar$ Geochronology of Air-Fall Ashes from the Miocene Pelagic Sequence of the Umbria–Marche Apennines (Italy), in *Abstracts, Eighth Int. Conf. on Geochron. Cosmochron. and Isotope Geol., Berkley, Calif., United States, June 5–11, 1994*, US Geol. Surv., 1994, Circular 1107, p. 373.

Dunning, G.R., Kean, B.F., Thurlow, J.G., and Swinden, H.S., Geochronology of the Buchans, Robert Arm, and Victoria Lake Groups and Mansfield Cove Complex, Newfoundland, *Can. J. Earth Sci.*, 1987, vol. 24, no. 6, pp. 1175–1184.

Dunning, G.R. and Krogh, T.E., Stratigraphic Correlation of the Appalachian Ordovician Using Advanced U–Pb Zircon Geochronology Techniques, *Pap. Geol. Surv. Can.*, 1991, no. 90-9, pp. 85–92.

Gorokhov, I.M., The Rb–Sr System in Volcanic Rocks, in *Izotopnoe datirovanie protsessov vulkanizma i osadkoobrazovaniya* (The Isotope Dating of Volcanic and Sedimentation Processes), Moscow: Nauka, 1985, pp. 18–44.

Gorokhov, I.M., Clauer, N., Turchenko, T.L., *et al.*, Rb–Sr Systematics of Vendian–Cambrian Claystones from the East European Platform: Implications for a Multi-Stage Illite Evolution, *Chem. Geol.*, 1994, vol. 112, no. 1/2, pp. 71–89.

Harland, W.B., Armstrong, R.L., Cox, A.V., *et al., A Geologic Time Scale 1989*, Cambridge: Cambridge Univ. Press, 1990.

Harland, W.B., Cox, A.V., Llewellin, P.G., *et al., A Geologic Time Scale*, Cambridge: Cambridge Univ. Press, 1982.

Harland, W.B., Francis, E.H., and Evans, R., The Phanerozoic Time-Scale, A Supplement, *Geol. Soc. Lond., Spec. Publ.*, 1971, no. 5.

Harland, W.B., Smith, A.G., and Wilcock, B., The Phanerozoic Time-Scale (A Symposium Dedicated to Professor Arthur Holms), *Q. J. Geol. Soc. London*, 1964, no. 3.

Hess, J.C., Lippolt, H.J., and Borsuk, A.M., Constraints on the Jurassic Time Scale by $^{40}Ar/^{39}Ar$ Dating of North Caucasian Volcanic Rocks, *J. Geol.*, 1987, vol. 95, no. 4, pp. 563–571.

Isachsen, C.E., Bowring, S.A., Landing, E., and Samson, F.D., New Considerations on the Division of Cambrian Time, *Geology*, 1994, vol. 22, no. 6, pp. 496–498.

Landing, E., Precambrian–Cambrian Boundary Global Stratotype Ratified and a New Perspective of Cambrian Time, *Geology*, 1994, vol. 22, no. 2, pp. 179–182.

Montanari, A., Coccioni, R., and Odin, G.S., Integrated Study of the Miocene Time Scale, in *Abstracts, Eighth Int. Conf. on Geochron. Cosmochr. and Isotope Geol., Berkley, Calif., United States, June 5–11, 1994*, US Geol. Surv., 1994, Circular 1107 p. 223.

Montanari, A. and Swisher, C., Radioisotopic Calibration of the Paleocene–Eocene Bio-Magnetostratigraphic Sequence at Gubboi (Italy), *ibid.*, p. 224.

Morozova, I.M., Araklyants, M.M., and Rublev, A.G., The K–Ar Systems of Volcanites, in *Izotopnoe datirovanie protsessov vulkanizma i osadkoobrazovaniya* (Izotope Dating of Volcanic and Sedimentation Processes), Moscow: Nauka, 1985, pp. 44–59.

Mundil, R., Brack, P., Meier, M., and Overli, F., Calibration of Time Scale and Sedimentary Cycles: High Resolution Single–Crystal U–Pb Age Determinations on Mid-Triassic Tuffs of the Southern Alps, *US Geol. Surv.*, 1994, Circular 1107, p. 229.

Numerical Dating in Stratigraphy, Odin, G.S., Ed., Chichester: Wiley, 1982.

Odin, G.S., Geological Time Scale (1994), *C. R. Acad. Sci., Ser. 11*, Paris, 1994, vol. 318, pp. 59–71.

Odin, G.S., How to Measure Glaucony Ages, *Numerical Dating in Stratigraphy*, Odin, G.S., Ed., Chichester: Wiley, 1982a, pp. 387–403.

Odin, G.S., The Phanerozoic Time Scale Revisited, *Episodes*, 1982b, no. 3, pp. 3–9.

Odin, G.S., Barbin, V., Hurford, A.J., *et al.*, Multi-Method Radiometric Dating of Volcano-Sedimentary Layers from Northern Italy: Age and Duration of the Priabonian Stage, *Earth Planet. Sci. Lett.*, 1991, vol. 106, no. 1/4, pp. 151–168.

Palmer, A.R., The Decade of North American Geology, 1983 Geologic Time Scale, *Geology*, 1983, vol. 11, no. 9, pp. 503–504.

Pushkarev, Yu.D., Kravchenko, E.V., and Shestakov, G.M., *Geokhronologicheskie repery dokembriya Kol'skogo poluostrova* (Geochronological Markers of the Precambrian in the Kola Peninsula), Leningrad: Nauka, 1978.

Rublev, A.G., Isotopic-Geochronological Models in K–Ar Geochronology, *Tr. Vses. Geol. Inst., Nov. Ser.*, 1984, vol. 328, pp. 4–23.

Rublev, A.G., On the Problem of Duration of Magmatic Processes, in *Evolyutsiya sistemy kora–mantiya* (Evolution of the Crust–Mantle System), Moscow: Nauka, 1986, pp. 135–148.

Shanin, L.L., Volkov, V.N., Litsarev, M.A., *et al., Kriterii nadezhnosti metodov radiologicheskogo datirovaniya* (Criteria of Reliable Methods of Radiological Datings), Moscow: Nauka, 1979.

Snelling, N.J., An Interim Time-Scale, The Chronology of the Geological Record, *Mem. Oxford Geol. Soc.*, 1985, no. 10, pp. 261–265.

Steiger, R.H. and Jager, E., Subcommission on Geochronology: Convention on the Use of Decay Constants in Geo- and Cosmochronology, *Earth Planet. Sci. Lett.*, 1977, vol. 36, no. 2, pp. 359–362.

Stratigraficheskii kodeks (The Stratigraphic Code), Zhamoida, A.I., Ed., St. Petersburg: Mezhved. Strat. Kom., 1992.

The Chronology of the Geological Record, Snelling, N.J., Ed., *Mem. Oxford Geol. Soc.,* 1985, no. 10, pp. 1–343.

Tucker, R.D., Krogh, T.E., Ross, J.R., and Williams, S.H., Time Scale Calibration by High Precision U–Pb Zircon Dating of Interstratified Volcanic Ashes in the Ordovician and Lower Silurian Stratotypes of Britain, *Earth Planet. Sci. Lett.*, 1990, vol. 100, pp. 51–58.

Williams, I.S., Tetlev, T.N., Compston, C.W., and McDougall, I., A Comparison of K–Ar and Rb–Sr Ages of Rapidly Cooled Igneous Rocks: Two Points in the Paleozoic Time Scale Re-Evaluated, *J. Geol. Soc.* (London), 1982, vol. 139, no. 5, pp. 557–568.

Wyborn, D., Owen, N., Compston, W., and McDougall, I., The Laidlow Volcanics: a Late Silurian Point on the Geological Time Scale, *Earth Planet. Sci. Lett.*, 1982, vol. 59, pp. 99–100.

Yasamanov, N.A., An Experience in Compilation of Geologic Time Scale on the Basis of Cyclic Geologic Events and Astronomical Data, *Dokl. Ross. Akad. Nauk*, 1993, vol. 328, no. 4, pp. 487–489.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 535–539. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 14–19.
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Biozonal Standards: Calibration Principles, Degree of Sophistication, and Interregional Application (Silurian Graptolites)

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Abstract—Modern geology now concentrating its attention not at individual sections, but on paleocontinents in gross, and initiated global generalizations, appeals for a unified approach to model zonal scales usable as standards in the *"left"* biostratigraphic column of correlation schemes. The term *standard* means the universally accepted model widely used in correlation practice. Ideally, the *biozonal standard* should represent a continuous or integrated sequence, which is itemized in details within a particular region on the basis of identical criteria and similar characteristics used to identify boundaries between zones (the first occurrence level of index species). Available biozonal standards of many Phanerozoic systems are in fact the zonal scales of geological areas, where respective series and stages were distinguished for the first time. For the Silurian System, it is the scale of graptolite zonation in the Great Britain and Pragian basin. However, long experience and more serious requirements to the resolution potential of biostratigraphic units showed that in many cases the latter are insufficiently valid for the global correlation. It is decided that the International Subcommission on Silurian Stratigraphy should use a generalized graptolite zonation in current studies on correlation schemes for the Silurian paleogeographic reconstructions. This zonation includes well-traceable biostratigraphic zones of stratotype and other regions, some of which can be coupled into greater, but better correlative, zonal units. The respective scale is assumed to be temporary, including only those correlative units, which are necessary for paleogeographic reconstructions. Current efforts to verify regional zonations and to improve the global correlation of debatable units (upper Llandovery, lower Wenlock, and Ludlow) are oriented toward the calibration of a universal zonal standard with a high resolution potential.

Key words: *zone, zonal standard, boundaries, detailed units, resolution potential in correlation, Silurian, graptolites.*

The first zonation of Jurassic ammonites, which was distinguished by A. Oppel in stratigraphic sections of England, France, and Germany, was not empirical. Stratigraphy of that time was already based on two fundamental principles:

(1) Smith's principle (Smith, 1816, 1817) suggesting similarity of beds with identical fossils and known now as the *principle of biostratigraphic subdivision and correlation*;

(2) Sulavie–Smith's principle to consider fossil assemblages from deposits different in age as distinct, progressively replacing one another; some researchers (Stepanov and Mesezhnikov, 1979) define it as the *law of paleontological succession.*

For the Mesozoic geological systems, as well as for the Ordovician and Silurian, first biozonations were suggested almost at the moment of recognition of these stratigraphic subdivisions. However, in many other Phanerozoic systems, zonal units were distinguished much later, about a hundred years after their discovery, despite the fact that the zone had been already officially adopted as the minimal unit of the scale in 1900. For instance, the Cambrian and Carboniferous, which were discovered before other systems, were subdivided into zones in the second half of our century.

The real boom in zonal stratigraphy was in the 1950s and 1960s. It was a time of intensive geological mapping and deep drilling in covered areas of platforms; the Deep Sea Drilling Program of "Glomar Challenger" and detailed studies on marine Cenozoic deposits were also initiated in this period. Likewise, the oil geology of that time contributed much to the detailed biostratigraphy. In addition, the period in question is marked by systematic work on stratigraphic terminology and classification, which was especially active in this country and associated with names of L.S. Librovich, A.P. Rotai, and D.L. Stepanov. The foundation of the Interdepartmental Stratigraphic Committee at the end of the 1950s initiated works on compilation and unification of regional stratigraphic schemes. Initially, the zone was accepted as the local or provincial unit (Librovich, 1954), and somewhat later (Rotai, 1956) it was introduced into the general stratigraphic scale to take place as the minimal subdivision

of the stage. Afterward, this calibration scheme was authorized in stratigraphic codes of this country (*Stratigraficheskii ...*, 1977, 1992).

Beginning in the 1960s, the progress in international stratigraphic classification, terminology and procedure developed in a somewhat different direction under the influence of such authority as H. Hedberg. The respective idea was to delimit biostratigraphy and a new scientific branch such as chronostratigraphy (*International ...*, 1976) despite the fact that this was against traditions of the European stratigraphic school. According to these traditions and the evolution of our science, all the systems, series, and stages were distinguished and approved on the basis of the evolution of organisms. The new approach displaced these subdivisions (by definition, but not by essence) into another category independent of biostratigraphic characteristics. Precisely, this changed the formal status of biostratigraphic zones and the total biozonal sequence with respect to the stage, as the latter was accepted by the international scientific community as the unit of chronostratigraphic category. To replace the biozone, such units as chronozones were introduced as subordinate in hierarchy to the stages, however, none of them has ever been depicted in any Phanerozoic system. In addition, the chronozone and biostratigraphic zone are not equivalents, because the latter corresponds to the stratigraphic interval with particular paleontological features and cannot be distinguished by any other method. Based on different faunal groups, zonal scales continued to develop as independent biostratigraphic standards, whose subdivisions were not coordinated with other stratigraphic units. The sequences of zones detectable by orthostratigraphic and other faunal assemblages were left in the proper column of the general stratigraphic scheme, and, being mutually correlated, they represented the basic biostratigraphic framework for subdivision and correlation of geological deposits (*Zonal'naya ...*, 1991).

The new edition of the *International Stratigraphic Guide* (1994) considerably modified the category of chronostratigraphic units. Their hierarchical series ends here with such a unit as substage, which actually is at the place of the chronozone, and the latter is understood as a unit independent of the chronostratigraphic stage–substage hierarchy. At first glance, this decision seems to be retrogressive, because it means a lesser detailing of the standard scale. In fact, it is progressive owing to the admittance of the fundamental significance of the biostratigraphic zone as a basic and most detailed unit usable for the time correlation of deposits. The current purpose of biostratigraphy is to ameliorate biozonal standards and the resolution ability of their subdivisions for global correlations.

It is appropriate now to discuss the somewhat pretentious term *standard*, which is used rather freely nowadays. *Webster's Dictionary* (1977) presents several definitions of the term, among which the most appropriate for our discussion is recorded as follows: *"the model of particular level and quality chosen by general agreement, to which others must conform."* Ideally, the biozonal standard must represent a continuous or integrated sequence of particular faunal assemblages, which is itemized in most details within a particular region on the basis of identical criteria used to identify boundaries between subdivisions. The latter must have a well-delineated lower boundary supplemented with characteristics of zonal faunal assemblages and traceable geographic range (regional, provincial, or global). However, available biozonal standards of many Phanerozoic systems do not meet these requirements. A good example here is the Silurian graptolite zonation initially recognized in the middle of the last century (Koren and Kaljo, 1976; Koren, 1984).

The simplest way to select the graptolite zonation widely usable in the correlation of Silurian deposits is to revise the detailed scale of classical black shale regions in Great Britain and continental Europe. However, even here we meet certain difficulties. First of all, none of the known graptolite sequences is full enough to satisfy the majority of specialists. The scheme, which is most often used by interregional correlations, represents a combination of fragments of regional sequences studied in Great Britain (Lower Silurian), Great Britain and Poland (Ludlow), and Bohemia (Pridoli) (Teller, 1969; Urbanek, 1970; Rickards, 1976, 1989; Storch, 1994). Nonetheless, this integrated scale includes units of different substantiation: partial-, total-, and overlapping-range zones; dominant-taxon zones; and complex zones. During the last decade, detailed zonal schemes were calibrated in many other localities of graptolite facies outside the European type regions. e.g., in Central Asia, China, arctic Canada, and Russia. The correlation analysis of these schemes versus the European standard (Koren, 1984, 1994) demonstrated the following disadvantages of the latter:

(1) not all stratigraphic interval is subdivided here into well-substantiated zones;

(2) not every zone is of the global rank;

(3) subdivisions, and especially their boundaries, are substantiated on the basis of different principles, and this is responsible for the inadequate stratigraphic ranges of synonymous zones in different regions.

Calibration of the general stratigraphic scale of the Silurian system was completed about 10 years ago (Bassett, 1985), and the boundaries of all its subdivisions are accepted as corresponding to boundaries of graptolite zones. This implies the necessity to trace the global boundaries of stages and substages with the highest precision. The calibration of any general standard of graptolite zonation, which would incorporate modern detailed subdivisions of most complete regional sequences, is the subject of forthcoming studies. Nevertheless, the reliable sequence of graptolite zones is essential as a biostratigraphic tool for current international studies aimed at creating a unified

correlation scheme for global paleogeographic reconstructions (Johnson, 1993). This goal was recently achieved by the working group of the International Subcommission on Silurian Stratigraphy (Koren *et al.*, in press). The group suggested the generalized sequence, where the number of zonal subdivisions was reduced from 42 to 27, because some regional biostratigraphic zones of Great Britain and Bohemia, which are not well-traceable outside the type regions, are substituted by greater units (figure). Biohorizons, or particular levels of events in the graptolite evolution, were adopted on that occasion as the zonal boundaries. This generalized zonation ensures the sound range of the sequence lacking the overlapping units, since its zonal boundaries are identified by using the universal principle of the first-occurrence levels of index species. In this case, each zonal range indicates the stratigraphic interval extending up to the appearance level of the index species typical of the next zone, and they all are supplemented with characteristics of fossil assemblages. To improve global correlation, the working group renamed some traditional zones on the basis of taxonomic revisions and according to the significance of diagnostic taxa for the interregional correlations. The attained specification degree of units (approximately 0.5–1 Ma per zone) is sufficient for factual global correlations of sections diverse in facies and displaying inadequately complete paleontological characteristics. The accepted graptolite zonation is correlated with zonal scales based on conodonts, chitinozoans, acritarchs, and vertebrates (*Silurian ...*, 1994). As a result, the constituent units of the scale are approaching the correlation potential of chronozones in the understanding that is recommended by the last edition of the *International Stratigraphic Guide* (1994).

At the same time, the suggested general graptolite zonation is invalid for solving problems of most detailed subdivision and correlation of graptolite facies. Accordingly, the Silurian Subcommission and special working groups are now involved in the International Project: "Silurian Graptolite Zonation of High Resolution Capacity."

What are the basic points to be considered in the work on such a standard?

(1) Despite the relatively cosmopolitan character of Silurian graptolites, the growing data base reveals some changes in composition of their species assemblages. So far the reasons are unclear, however, these changes are distinctly below the provincial rank. Nonetheless, when calibrating the details of the general standard, we should test all the facial environments and latitudinal belts without any *a priori* disregard of the ability of graptolites to be differentiated in the paleogeographic, or biofacial sense. This means in practice that we must concentrate our attention not only on similar, but also on distinct features of coeval assemblages. It is necessary as well to avoid additional troubles, such as the imperfect sampling of sections, taxonomic misinterpretations, and misleading correlations.

(2) The assumed ecological control on graptolite taxa distribution in their lifetime, e.g., along the bathymetric gradient (epipelagic, mesopelagic, and bathyal assemblages), is to be always taken into account in detailed correlations of hemipelagic and pelagic beds. The appropriate attempts may include studies on parallel zonal sequences for identical stratigraphic intervals based on different graptoloid taxa (monograptids and diplograptids of the Llandovery; monograptids and plectograptids of the upper Wenlock).

(3) The improvement of regional zonal scales is the only way to create the general standard. In every region, investigations are based on the best studied section displaying distribution ranges of diagnostic taxa. Such a section must ideally comprise the entire stratigraphic interval of interest, whose paleontological characteristics are well and uniformly documented. However, such representative sections are rare; in many regions they are unknown, and more general zonation is based here, as usual, on integrated local sequences. The detailed comparison and correlation of all studied localities in a region decreases possible determination errors for the appearance and extinction levels of graptolite taxa. Therefore, the integrated sequence of regional biozones is more reliable than a single section, because its zonal boundaries are considerably less dependent on unfavorable local factors, such as inappropriate sedimentary facies, or unsatisfactory samples of fossils.

Now, one may ask, what methodology is suitable to compile the standard?

The irregular distribution of graptolites in concrete sections is the very case in which only traditional methods are applicable. Fossil assemblages from a particular section usually include 6–10 species per every interval, whereas the general diversity of zonal faunas is estimated as corresponding to dozens of taxa. The graphic correlation, or statistical methods, are hardly applicable to the graptolite sequence, because the number of appearance and extinction levels in a local section is insufficient for a serious analysis. A more useful way to evaluate the correlation significance of biohorizons is to collate their relative ranges in sections corresponding to different sedimentation environments. This is an important test; when those ranges are identical, they imply that the revealed sequence of events responsible for the appearance and extinction of taxa is approaching the biochronological succession, and is usable for the time correlation.

And finally, what are subsequent stages of study aimed at improving the general standard of graptolite zonation?

(1) It is necessary to select debatable intervals of the graptolite sequence and those areas, which comprise the most complete sections of respective deposits and may serve as the type regions in the future. For most

Pridoli		*bouceki-transgrediens*	*	x
		branikensis-lochkovensis	*	x
		parultimus-ultimus	*	x
Ludlow	Ludfordian	*formosos*	*	p
		bohemicus tenuis-kozlovskii	*	x
		leintwardinensis	*	t
	Gorstian	*scanicus*	*	t
		nilssoni	*	p
Wenlock	Homerian	*ludensis*	*	t
		praedeubeli-deubeli	*	x
		parvus-nassa	*	x
		lundgreni	*	t
	Sheinwoodian	*rigidus-pemeri*	*	x
		riccartonensis-belophorus	*	x
		centrifugus-murchisoni	*	x
Llandovery	Telychian	*lapworthi-insectus*	*	x
		spiralis interval		i
		griestoniensis-crenulata	*	x
		turriculatus-crispus	*	x
		guerichi	*	?p
	Aeronian	*sedgwickii*	*	p
		convolutus	*	t
		argenteus	*	p
		triangulatus-pectinatus	*	x
	Rhuddanian	*cyphus*	*	t
		vesiculosus	*	p
		acuminatus	*	?t

Generalized sequence of graptolite zones: (x) zonal units combining several regional zones; (t) total-range zones of index species distribution; (p) partial-range zones of index species distribution (zonal units, whose lower boundary is defined by the first occurrence level of index species, are marked by asterisk).

large stratigraphic intervals, the sections of interest must be composed of sedimentary facies favorable for graptoloids. In this case, stratigraphic ranges of taxa will provide the most reliable data on their existence periods.

(2) It is necessary to study and to intercorrelate local sections in order to compile a generalized scheme depicting the appearance levels of diagnostic taxa and the degree of overlapping of their stratigraphic ranges in the type regions. As was already noted, the integrated regional scheme is better at elucidating boundaries between zones than any local one, even the most complete section.

(3) We should test biohorizons, which are appropriate to identify the zonal boundaries, by means of critical comparison with all other well-studied localities, and within every stratigraphic interval.

(4) All available data on reconstructed phylogenetic lineage, and all the results of taxonomic revision must be taken into account by the biochronological calibration of the Silurian graptolite zonation.

CONCLUSION

The instructive experience with Silurian zonal stratigraphy of graptolites can be successfully used to study zonation of other faunal groups in different Phanerozoic systems. It leads me to conclude the following:

(1) Zonal standards for different groups of fossils represent individual scales independent of hierarchical subdivisions of any other type. Zonal units can be enlarged or internally subdivided for a particular purpose, if they are adequately studied. The progress in our knowledge of the evolution, taxonomy, and phylogeny

of fauna leads to the permanent improvement and detailing of zonal standards and biostratigraphy.

(2) Independent zonal standards of identical stratigraphic intervals, which are based on different faunal groups, are suitable to control one another. Less effective are standards, whose subdivisions are of complex substantiation, i.e., based on the combination of two or more groups of fossils.

(3) The standard zonal units should be defined and validated by identical criteria, among which the first occurrence level of the zonal taxon is the most important for the determination of zonal boundaries.

(4) The persistent correction of regional scales is the basic procedure of the revision and sophistication of biozonal standards.

(5) When selecting diagnostic zonal taxa, one should prefer taxonomic groups with well-established phylogenetic relations. The conodont zones of the Lower Devonian, which are based on the distribution of icriodids and polygnathids, or the Upper Devonian zonation of palmatolepids are good examples of such analyses.

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REFERENCES

Bassett, M.G., Towards a "Common Language" in Stratigraphy, *Episodes*, 1985, vol. 8, no. 2, pp. 87–92.

International Stratigraphic Guide. A Guide to Stratigraphic Classification, Terminology, and Procedure, Hedberg, H., Ed., New York: Wiley, 1976.

International Stratigraphic Guide. A Guide to Stratigraphic Classification, Terminology, and Procedure, Salvador, A., Ed., Geol. Soc. Am., 1994.

Johnson, M.E., Second International Symposium on the Silurian System, *Lethaia*, 1993, vol. 26.

Koren, T.N., A Simplified Graptolite Zonal Sequence—Reliable Levels for Global Paleogeographic Reconstructions, in *IUGS Subcommission on Silurian Stratigraphy: Field Meet., 1994*, Vienna: Bibl. Geol. B.–A., 1994, pp. 3–9.

Koren, T.N., Graptolite Zones and Standard Stratigraphic Scale of Silurian, in *Proc. 27th Int. Geological Congr.: Stratigraphy*, VHU Science, 1984, pp. 47–76.

Koren, T.N. and Kaljo, D.L., Graptolite Zonal Scale for the Silurian System, in *Graptolity i stratigrafiya* (Graptolites and Stratigraphy), Tallinn: Valgus, 1976, pp. 64–84.

Koren, T.N., Lenz, A.C., Loydell, D.K., Melchin, M.J., Storch, P., and Teller, L., Generalized Graptolite Zonal Sequence Defining Silurian Time Intervals for Global Palaeogeographical Studies, *Lethaia* (in press).

Librovich, L.S., *Stratigraficheskie i geokhronologicheskie podrazdeleniya. Ikh printsipy, soderzhanie, terminologiya i pravila primeneniya* (Stratigraphic and Geochronological Subdivisions: Principles, Meaning, Terminology, and Application Rule), Moscow: Gosgeoltekhizdat, 1954.

Rickards, R.B., Exploitation of Graptoloid Cladogenesis in Silurian Stratigraphy, *Nat. Mus. Wales Geol. Ser.*, 1989, no. 9, pp. 265–274.

Rickards, R.B., The Sequence of Silurian Graptolite Zones in the British Isles, *Geol. J.*, 1976, vol. 11, pt. 2, pp. 153–188.

Silurian Times. A Newsletter of the Silurian Subcommission, Int. Comm. Stratigr. IUGS, 1994, no. 2.

Smith, W., *Strata Identified by Organized Fossils*, London: W. Arding, 1816.

Smith, W., *Stratigraphical System of Organized Fossils with Reference to the Specimens of the Original Geological Collection of the British Museum*, London, 1817.

Stepanov, D.L. and Mesezhnikov, M.S., *Obshchaya stratigrafiya: Printsipy i metody stratigraficheskikh issledovanii* (General Stratigraphy: Principles and Methods of Stratigraphic Studies), Leningrad: Nedra, 1979.

Storch, P., Graptolite Biostratigraphy of the Lower Silurian (Llandovery and Wenlock) of Bohemia, *Geol. J.*, 1994, vol. 29, pp. 137–165.

Stratigraficheskaya klassifikatsiya i terminologiya (Stratigraphic Classification and Terminology), Rotai, A.P., Ed., Moscow: Gosgeoltekhizdat, 1956.

Stratigraficheskii kodeks SSSR. Vremennyi svod pravil i rekomendatsii (Stratigraphic Code of the USSR. Temporary Compendium of Rules and Recommendations), Zhamoida, A.I., Ed., Leningrad: Vses. Geol. Inst., 1977.

Stratigraficheskii kodeks. Izdanie vtoroe, dopolnennoe (Stratigraphic Code. Second Edition, Supplemented), St. Petersburg: Mezhved. Strat. Com., 1992.

Teller, L., The Silurian Biostratigraphy of Poland Based on Graptolites, *Acta Palaeontol. Polonica*, 1969, vol. 19, pp. 393–502.

Urbanek, A., Neocucullograptinae n. subfam. (Graptolithina): Their Evolutionary and Stratigraphic Bearing, *Acta Palaeontol. Polonica*, 1970, vol. 15, pp. 164–338.

Webster's New Twentieth Century Dictionary of the English Language Unabridged, Collins World, 1977, 2nd ed.

Zonal'naya stratigrafiya fanerozoya SSSR: Spravochnoe posobie (Phanerozoic Zonal Stratigraphy of the USSR: Reference Book), Koren, T.N., Ed., Moscow: Nedra, 1991.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 540–551. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 20–31.
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The Midian Stage of the Permian and Its Boundaries

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Abstract—The Midian Stage is suggested to correspond to the *Yabeina–Lepidolina* Genozone, i.e., to the entire existence time of the index genera. The first occurrence level of *Yabeina* forms is in the *Neoschwagerina margaritae* Zone in its stratotype section, and this zone should be considered as a constituent unit of the stage. This is also evident from a significant renewal of fusulinid and smaller foraminifer assemblages at the base of indicated zone, which was caused by a widespread transgression. The *Lepidolina kumaensis* Zone should be included into the Midian Stage as well. At present, none of the fauna groups seem to be suitable to precisely determine the stage boundaries. This problem remains to be solved in the future.

Key words: *stratigraphy, fusulinids, the Permian System, stage, Tethys, correlation.*

INVESTIGATION HISTORY OF THE MIDIAN STAGE

In 1958, Miklukho-Maclay (1958) distinguished the Murgabian Stage as a unit comprising the *Neoschwagerina, Sumatrina*, and *"Polydiexodina"* beds (Table 1). The Djamantal, Deire, and Karasu beds were later included in this stage according to data on the stratotype section of the Murgab River basin (Mt. Djamantal), and the southeastern Pamirs (Leven, 1967). The upper Kutal Beds along with the overlying Takhtabulak Formation were referred here to the Pamirian Stage.

Miklukho-Maclay reported on fusulinids from the Djamantal and Karasu beds. Neoschwagerinids were most characteristic among them, however, he did not attest to the presence of *Yabeina* and *Lepidolina*, which are the most evolved genera of this group. Nevertheless, Miklukho-Maclay decided to include into Murgabian Stage not only the *Neoschwagerina*, but also the *Yabeina* Beds, as it is evident from his correlation schemes (Miklukho-Maclay, 1963). In the overlying Pamirian Stage, fusulinids are represented only by smaller, often aberrant forms, and all their larger representatives were assumed to become extinct at the Murgabian–Pamirian boundary.

The evident discordance between the factual data on the stratotype and Miklukho-Maclay's idea to include the *Yabeina* Beds into the Murgabian Stage caused a serious, still on going discussion concerning the upper boundary of this stage. The later discovery of *Yabeina archaica* from the Karasu Beds (Dutkevich, 1967; Leven, 1967), which somehow supported the concept of including the *Yabeina* Beds in the stage, did not improve the general situation. The primitive character of this *Yabeina* species leaves room for considering it as the first indication of a younger fusulinid assemblage of the *Yabeina–Lepidolina* Genozone. Moreover, the Karasu Beds are composed of clastic limestones, mostly conglobreccias presumably of turbidity origin.

Table 1. Evolution of ideas on stratigraphic ranges of Murgabian and Midian stages

Miklukho-Maclay (1958, 1963)	Leven (1963)	Leven (1975)	Leven (1980)
Pamirian Stage *Reichelina* and smaller foraminifers	Pamirian Stage *Lepidolina, Yabeina*	Changhsinghian Stage	Dorashamian Stage
		Dzhulfian Stage	Dzhulfian Stage
Murgabian Stage *Neoschwagerina, Sumatrina, "Polydiexodina"*		Capitanian Stage *Yabeina, Lepidolina*	Midian Stage *Yabeina, Lepidolina*
	Murgabian Stage *Neoschwagerina, Sumatrina, "Polydiexodina"*	Murgabian Stage *Neoschwagerina*	Murgabian Stage *Neoschwagerina*
Darvazian Stage *Cancellina, Misellina*	Kubergandian Stage *Cancellina, Armenina, Misellina*	Kubergandian Stage *Cancellina*	Kubergandian Stage *Cancellina, Armenina, Misellina ovalis*

They bear mainly redeposited fusulinids, and this occurrence mode may be assigned to *Yabeina archaica* as well.

Compiling data on the Tethys in 1963, I noted that many smaller and aberrant fusulinids typical of the Pamirian Stage alone, as suggested by Miklukho-Maclay, show their first occurrence in the *Yabeina–Lepidolina* Genozone. This was my argument for including the latter into the Pamirian Stage (Leven, 1963). This idea did not contradict the available data on the stratotype of the Murgabian Stage, although its range in this case differed from that suggested by Miklukho-Maclay.

The new scale of more detailed stage subdivisions for the Tethyan region was published in 1975 (Leven, 1975a). In this scale, the *Yabeina–Lepidolina* Genozone was identified as an individual stage corresponding to the Capitanian Stage of the North American scale, and the latter name was accepted. However, discussing the new scale at the plenary session in 1980, the Interdepartmental Stratigraphic Committee (ISC) of the former USSR doubted the identity of the newly distinguished and Capitanian stages. When editing afterward the explanatory note to the Tethyan scale, I changed the unit name for the Midian Stage (Leven, 1980). The Arpa and Khachik formations of the Permian in Transcaucasia were suggested to be the unit stratotype, and, with the last name, the stage was authorized by the ISC (*Postanovleniya* ..., 1981).

According to the initial definition, the Midian Stage includes the sequence part between the Murgabian and Dzhulfian stages, which corresponds to the *Yabeina–Lepidolina* Genozone. The lower stage boundary is placed at the first occurrence level of extremely evolved higher fusulinids of *Yabeina* and *Lepidolina* genera, which also mark the mass abundance of aberrant forms. Such taxa as *Kahlerina, Dunbarula, Paradunbarula, Lantschichites, Chusenella, Sumatrina, Metadoliolina* along with extremely evolved *Neoschwagerina* and some other forms were listed as most characteristic of the stage (Leven, 1980).

The upper stage boundary was identified as corresponding to the base levels of the *Araxoceras latum* Zone of the ammonite zonation (including the *Araxilevis* Beds of the Dzhulfian Stage stratotype) and *Clarkina leveni* Zone of the conodont scale. It was suggested that this boundary should mark the total extinction of schwagerinids and neoschwagerinids, although there were other opinions concerning its significance.

FURTHER STUDIES ON THE MIDIAN STAGE AND RELATED PROBLEMS

After publication of the Tethyan scale with the newly introduced Midian Stage (Leven, 1980), numerous later stratigraphic and paleontologic works provided grounds to considerably specify its characteristics and to distinguish it in different regions from the Mediterranean to the Far East and Japan. At the same time, new data yielded certain problems, first of all concerning the inadequate interpretation of the stage boundaries and its stratigraphic range.

First, I would like to mention the investigations of the scientific group under Kotlyar's leadership, whose monograph (Kotlyar *et al.*, 1989) presents comprehensive paleontologic substantiation of the Midian Stage based on type sections in the Transcaucasia, Pamirs, and the Far East. These researchers correlated the Midian deposits throughout the Tethys and confirmed the original characteristics of the stage. The sole difference is the statement on a somewhat lower position of its upper boundary, and I discuss this point below in more detail.

Japanese scientists, led by K. Nakazawa, also performed a large study of the Upper Permian. The group (Nakazawa *et al.*, 1975; *Iranian-Japanese* ..., 1981; *Pakistan-Japanese* ..., 1985) published detailed descriptions of sedimentary sequences in Iran, Kashmir, and the Salt Range, and demonstrated that they really include deposits of the Midian Stage. Publications of Chinese and French researchers (Zhang Zugi, 1984; Xiao *et al.*, 1986; Sheng and Jin Yugan, 1994; Lys, 1988a; Vachard and Ferrière, 1991; Vachard and Razgallah, 1993) explored further the paleontologic characteristics of the stage in different Tethyan regions. Because the Midian Stage is identified as an equivalent of the *Yabeina–Lepidolina* Genozone, the works of Ozawa (1975), Kobayashi (1986), and Rui Lin (1983) are of special interest for the description of the phylogeny and stratigraphic distribution of zonal index species. In addition, I should mention several works dealing with problems of the Midian Stage boundaries in their relation to one or another geological and biotic event (Kotlyar *et al.*, 1989; Leven, 1992, 1993a, 1993b; Jin Yugan *et al.*, 1994b, Mei Shilong *et al.*, 1994; Kozur, 1994; Vachard and Ferrière, 1991).

All these studies confirmed the individual and peculiar character of the Midian Stage in the geological history of the Tethys. This stage marked a wide transgression, which resulted in a substantial renewal of marine biota, extended its distribution areas, and gave rise to a higher taxonomic diversity of principal faunal groups. Sedimentary sequences, which were studied in various parts of the Tethys, showed that the Midian Stage can be recognized throughout this region. Its paleontologic characteristics were carefully refined and substantiated, and new results allowed the correlation of data on fusulinids, smaller foraminifers, brachiopods, ammonoids, and conodonts.

At the same time, it should be noted that current ideas on the stratigraphic range of the Midian Stage and criteria to distinguish its boundaries are controversial for several reasons. Boundaries of the *Yabeina–Lepidolina* Genozone, which corresponds to the Midian Stage by definition, are not determined very precisely. General principles of tracing the stage boundaries in

Table 2. Stratigraphic schemes of the Akasaka section after different authors

Deprat, 1914	Ozawa, 1927	Morikawa, 1958	Hongo, 1959
Y. inoyei *Y. globosa*	*Y. globosa*	*N. minoensis* *Y. inoyei* *"Y." katoi* *Y. globosa*	*Y. globosa*
"N. globosa" *(=G. gifuensis)* *"N. margaritae"* *(=Y. ozawai)*	*"N. margaritae"* *(=Y. ozawai)*	*Y. (=L.) igoi* *N. (=G.) larga* *"N. margaritae"*	*G. douvillei* *G. gifuensis* *Y. ozawai*
"N. craticulifera"	*"N. craticulifera"*	*"N. craticulifera"*	*"N. craticulifera"*

concrete sections lacking index species of the zone are unclear. The upper boundary of the Midian and the lower boundary of the Dzhulfian stages are identified on the basis of fusulinids and ammonoids, respectively, and it is difficult to coordinate these different criteria. Finally, stratotypes of the Midian and Murgabian stages are poorly chosen, and this allows for personal interpretations. We shall consider these points in more detail below.

YABEINA–LEPIDOLINA GENOZONE: DISTINGUISHING CRITERIA AND CHARACTERISTIC FUSULINIDS

The *Yabeina–Lepidolina* Genozone corresponds to the Midian Stage by definition, and it is important to specify its actual meaning.

Originally, the stratigraphic range of the genozone was identified by a theoretical approach. It was thought to comprise the total evolutionary interval of index genera, whose appearance and extinction were presumably coeval with large reorganization stages in fusulinid biota. It was and remains precisely this principle, which affords an opportunity to speculate on the distinctive Midian Stage in the Tethys evolution.

As usual, reality turned out to be more complex than the hypothesis. It does not disprove the latter in general, but complicates many particular problems, among which the precise determination of appearance and extinction levels of *Yabeina* and *Lepidolina* forms is the most important. Yabeins and lepidolins in particular were most abundant in the eastern Tethys (southern China, Indochina, Japan, and the Far East). They occur as components of different fusulinid assemblages, whose relations in space and time are debatable. Understanding these relations, we may solve general problems concerning the Midian Stage. Using typical representatives of *Yabeina* and *Lepidolina* genera, it is possible to subdivide the studied assemblages into the four following types: (1) *Y. ozawai–L. igoi*, (2) *Y. globosa*, (3) *L. multiseptata*, and (4) *L. kumaensis*.

The first assemblage was distinguished in the classical Akasaka section of Japan, precisely in beds corresponding to the *Neoschwagerina margaritae* Zone after Ozawa (1927). Honjo (1959) discovered yabeins at the base of the beds, and identified them as representing the new species *Y. ozawai*. He also noted that forms, distinguished by Ozawa as *N. margaritae* Deprat, are not identical to the holotype of Deprat (1913), and represent a synonym of the new *Yabeina* species. Accordingly, this scientist renamed the *N. margaritae* Zone as the *Y. ozawai* Zone.

Honjo discovered yabeins only from the basal part of the zone. Its upper part (Table 2) was better studied by Morikawa and Suzuki (Morikawa, 1958; Morikawa and Suzuki, 1961). In the corresponding part of the section, Morikawa distinguished *Neoschwagerina margaritae* Deprat, *"N."* (=*Gifuella*) *larga* Morikawa et Suzuki, and *"Yabeina"* (=*Lepidolina*) *igoi* Morikawa et Suzuki beds, or zones in his terms. The first of these units correlates well with the *Y. ozawai* Beds of Honjo's scheme, because they yielded the same *Gifuella* forms: *G. amicula* Honjo (=*"N." muratai* Morikawa et Suzuki). In overlying beds, this taxon shows a higher organization. The *"N."* (=*G.*) *larga* Beds contain remains of *Yabeina?* sp.; *"Y."* (=*L.*) *igoi* occurring higher in the section is the descendant of *G. larga*, and differs from the latter only by its secondary spiral septula. This level also bears first *"Y."* (=*L.*) *multiseptata* (Deprat). Thus, the entire interval of the *N. margaritae* Zone after Ozawa contains yabeins and lepidolins. In addition to them and the *Gifuella* forms already mentioned, this interval also yielded *Gifuella gifuensis* Honjo, *G. douvillei* Ozawa, *Neoschwagerina margaritae* Deprat, *N. colaniae* Ozawa, *N. minoensis* Deprat, *N. sakaguchii* Yamagiwa, *Pseudodoliolina* spp., *Verbeekina* spp., *Parafusulina* spp., *Pseudofusulina* spp., and *Codonofusiella* spp. It should be noted that some forms, pictured in cited publications and identified as *N. margaritae*, were mistaken for this taxon, because they have more primitive aspects as compared to the holotype (Leven, 1993b).

The next *Y. globosa* fusulinid assemblage was reported from the higher level of the same section. In addition to *Y. globosa* (Yabe), it includes *Yabeina inouyei* Deprat, *Neoschwagerina katoi* Ozawa, *N. mar-*

garitae Deprat, *N. minoensis* Deprat, *"N."* (= *Gifuella*) *okuboi* Morikawa et Suzuki, *"N."* (= *G.*) *hanaokensis* Morikawa et Suzuki, *Sumatrina annae* Volz, *Parafusulina* spp., *Pseudofusulina* spp., and *Kahlerina* spp. (Deprat, 1914; Ozawa, 1927; Morikawa, 1958; Honjo, 1959; Hanzawa and Murata, 1963). Fusulinids, which were discovered by Kobayashi (1986) from the Gozeniyama Formation of the southern Kwanto Mountains, may also represent the same assemblage. Reported from here are the following forms: *Yabeina globosa* (Yabe), *Neoschwagerina minoensis* Deprat, *"Colania"* (= *Gifuella*) *larga* (Morikawa et Suzuki), *Verbeekina verbeeki* Geinitz, *Chusenella* spp., *Pseudofusulina* spp., *Dunbarula* spp., *Paradoxiella* spp., *Rauserella* spp., *Sichotenella* spp., *Reichelina* spp., *Nankinella* spp., and *Kahlerina* spp. Using a large data base, Kobayashi elaborated the considerable morphologic diversity of *Y. globosa* species. In his opinion, *Y. inouyei* and *N. katoi* from the Akasaka section are synonyms and represent morphologic varieties of this species. In addition, the assemblage under consideration includes many smaller and aberrant fusulinids typical of the Midian Stage.

The *L. multiseptata* fusulinid assemblage is the most widespread in southeastern Asia. Its general characteristics were reported by Ozawa (1975). Dominant representatives of this assemblage belong to the *Gifuella–Lepidolina* phylogenetic lineage in contrast to the previous assemblage with prevailing *Neoschwagerina* and *Yabeina* forms, whose phylogenetic evolution was coeval. The compiled list of genera and species occurring together with fusulinids of *L. multiseptata* group in many localities of Japan (Toriyama, 1954, 1958; Ozawa, 1975), China (Sheng, 1963; Xiao *et al.*, 1986), and Indochina (Ishii, 1966; Ishii *et al.*, 1969; Ozawa, 1975; Toriyama *et al.*, 1975; Tien, 1979; Ingavat *et al.*, 1980; Toriyama, 1984; and others) is as follows: *Gifuella douvillei* (Ozawa), *Neoschwagerina cheni* Sheng, *N. margaritae* Deprat, *N. kueichowensis* Sheng, *N. haydeni* Dutkevich et Khabakov, *Sumatrina annae* Volz, *S. longissima* Deprat, *S. fusiformis* Sheng, *Pseudodoliolina pseudolepida* (Deprat), *Metadoliolina multivoluta* (Sheng), *M. gravitesta* (Kanmera), *Verbeekina verbeeki* (Geinitz), *Eopolydiexodina* spp., *Parafusulina* spp., *Pseudofusulina* spp., *Chusenella* spp., *Schubertella* spp., *Dunbarula* spp., *Codonofusiella* spp., *Lantschichites* spp., *Sichotenella* spp., *Reichelina* spp., *Nankinella* spp., and *Staffella* spp.

The *L. kumaensis* assemblage is known only in some sections (Kuma, Shikoku, southeastern Kwanto, and Iwaizaki) of Japan (Ozawa, 1975) and the Far East (Kotlyar *et al.*, 1989). The most representative assemblage was reported from Primor'e, where *L. kumaensis* Kanmera occurs in the *Parafusulina stricta* and *Metadoliolina lepida–Lepidolina kumaensis* zones of the Chandalaz Horizon (Kotlyar *et al.*, 1989). The cited authors believed that this form is also present in the underlying *Monodiexodina sutschania–Metadoliolina dutkevitchi* Zone, however this assumption turned out to be invalid (G.V. Kotlyar, personal communication). It was proved that the first occurrence level of *L. kumaensis* is in the *P. stricta* Zone. Above it, this form becomes abundant and attains its highest state of evolution giving rise to the new *Neosumatrina* genera (data of N.O. Chediya cited from Kotlyar *et al.*, 1989).

The composition of associated forms changes upward in the section. Representatives of the Schwagerinida order prevail near the base and lose their significance higher. *Metadoliolina* and *Lepidolina* forms are dominant among higher fusulinids especially in the upper zone. The latter comprise several varieties of *L. kumaensis* Kanmera and *L. multiseptata* Deprat typical of the aforementioned assemblage. The upper zone also yielded rare *Neoschwagerina* and several *Yabeina* species.

The assemblage of smaller fusulinids (including their aberrant forms) is very diverse and abundant. It includes different species of such genera as *Sichotenella, Reichelina, Parareichelina, Rauserella, Codonofusiella, Dunbarula, Minojapanella* (Wutuella), *Lantschichites, Kahlerina,* and *Pseudokahlerina*. It is significant that *Codonofusiella, Reichelina*, and *Sichotenella* forms show their appearance already in the *M. sutschanica–M. dutkevitchi* Zone, while those of *Lantschichites* and *Kahlerina* genera occur in the *P. stricta* Zone.

As it was already mentioned, relations between the described fusulinid assemblages in space and time are not very clear. Representative sections are rare, their outcrops with different fusulinid assemblages are spatially dismembered and confined to contrasted sedimentary facies. In addition, there is no commonly accepted view on fusulinid taxonomy and phylogenetic evolution. The latter does not fit the simple model of divergent evolution, but is more readily consistent with the idea suggesting a parallel development, in which forms, similar in their features and assigned on this basis to the same taxon (for instance, to yabeins), actually originated in parallel phylums and perhaps at different times because of distinct evolutionary rates.

The most detailed model of relations between distinct fusulinid assemblages was elaborated by Ozawa (1970, Fig. 2). For the stratigraphic range in question, he distinguished four assemblages: (1) *Neoschwagerina craticulifera*, (2) *Yabeina globosa*, (3) *Lepidolina multiseptata shiraiwensis–Colania* (= *Gifuella*) *douvillei*, and (4) *Lepidolina multiseptata multiseptata–L. kumaensis*. According to Ozawa, the first of them is characteristic of the second half of the Middle Permian, i.e., of the *N. craticulifera* and *N. margaritae* zones. The second and third are coeval, and correspond to the *Y. globosa* Zone of the Upper Permian. The *L. multiseptata multiseptata–L. kumaensis* assemblage is already of the Dzhulfian age.

I agree with Ozawa's conclusion that the *N. craticulifera* assemblage is the oldest among them, and would add only that its part, occurring in the *N. margaritae*

(= *Y. ozawai*) Zone, includes yabeins and lepidolins even here, as follows from data on the Akasaka section. There is no question that *Y. globosa* and *L. multiseptata shiraiwensis–C.* (=*G.*) *douvillei* assemblages are approximately coeval. Actually, first forms of the *L. multiseptata* group appear below the *Y. globosa* beds. Therefore, these beds are, at least partially, the appropriate level for the abundance of respective *Lepidolina* species.

The most complex problem is to identify the stratigraphic position of the *L. multiseptata multiseptata–L. kumaensis* beds. When placing them above the *Y. globosa* beds into the Dzhulfian Stage, Ozawa (1979, p. 39, Fig. 10) had in mind the higher evolutionary level of *L. kumaensis* as compared to any *Yabeina* forms. However, it is not inconceivable that progressive evolution toward thinner, but denser test walls and greater number of axial and secondary spiral septula was faster in the *Gifuella–Lepidolina* phylogenetic lineage as compared to that of *Neoschwagerina–Yabeina* taxa. In this case, *L. kumaensis* could be older in origin than was assumed by Ozawa, and this is supported by data on the Chandalaz Horizon in Primor'e. Nevertheless, it is not to be supposed that the uppermost beds bearing *L. kumaensis* (*M. lepida–L. kumaensis* Zone in Primor'e) are younger than the *Y. globosa* beds. Precisely, this interval of the sequence, but not the entire biozone of *L. kumaensis* species is usually termed as the *L. kumaensis* Zone in publications.

Rui Lin (1983), who discovered *L. kumaensis* in association with *L. multiseptata* from the middle part of the Maokou Formation in southern China, also was in favor of the earlier appearance of the former form. However, his arguments are not very correct, because fusulinids, which were identified in this case as *L. kumaensis*, are at a lower level of evolution relative to the authentic representatives of this species, and in this respect, they are more similar to *L. igoi* from the Akasaka section.

In summarizing the discussed data, I would like to state the following:

(1) *Yabeina* and *Lepidolina*—the index genera of the Midian Stage—are approximately coeval with respect to their appearance and extinction time.

(2)The *Yabeina–Lepidolina* Genozone comprises the stratigraphic interval from the *N. margaritae* Zone, first distinguished by Y. Ozawa, up to and including the *L. kumaensis* beds.

(3) Accordingly, by its original definition, the Midian Stage corresponds to this stratigraphic interval of the sequence.

(4) In such an understanding, the Midian Stage can be subdivided into three units: *Y. ozawai–L. igoi, Y. globosa–L. multiseptata*, and *L. kumaensis* (s.s.) zones. However, one should bear in mind that this subdivision is somewhat arbitrary, because boundaries between these zones have so far not been identified very precisely, and two upper zones may partially overlap each other.

(5) The fusulinid assemblage of the first zone is distinct because of the first appearance of primitive *Yabeina* and *Lepidolina* forms. It also includes abundant *Gifuella* species and such forms as *N. margaritae* Deprat (s.l.), *N. colaniae* Ozawa, *N. haydeni* Dutkevich et Khabakov, *N. craticulifera* (Schwager) (s.s). Associated taxa are *Pseudodoliolina, Verbeekina, Sumatrina annae* Volz, *S. fusiformis* Sheng, and the first representatives of *Metadoliolina*. It is likely that *Afghanella sumatrinaeformis* (Gubler) also occurs at this stratigraphic level. Schwagerinids are represented here by *Chusenella, Parafusulina, Pseudofusulina, Eopolydiexodina*, and possibly *Rugososchwagerina* and *Monodiexodina* genera. *Codonofusiella, Dunbarula, Rauserella, Reichelina*, and *Parareichelina* forms were recognized among smaller fusulinids.

The *Y. globosa–L. multiseptata* Zone is marked by an abundance of *Yabeina* and *Lepidolina* species. *L. kumaensis* seems to appear here. Representatives of the *Neoschwagerina* genus include highly evolved *N. margaritae* Deprat (s.s), *N. katoi* Ozawa, and *N. minoensis* Deprat. Such taxa as *Sumatrina longissima, Metadoliolina*, and *Verbeekina* occur frequently and associate with numerous *Chusenella, Pseudofusulina*, and *Parafusulina* forms. *Codonofusiella, Dunbarula, Lantschichites, Minojapanella (Wituella), Reichelina, Rauserella, Sichotenella*, and *Kahlerina* genera are abundant among smaller and aberrant fusulinids.

Lepidolina and *Metadoliolina* species are dominant in the *L. kumaensis* Zone. They associate with less abundant *Yabeina, Neoschwagerina, Parafusulina, Pseudofusulina*, and *Chusenella* forms. Like the previous zone, this one encloses approximately the same assemblage of smaller and aberrant fusulinids.

BOUNDARIES OF THE MIDIAN STAGE

At present, there is no doubt that the Midian Stage is a distinct stratigraphic unit, which can be traced nearly everywhere. However, problems concerning its boundaries are still unresolved.

For the lower boundary, I would reduce the problem to two main questions: (1) should we include the beds, which used to be referred to the *N. margaritae* Zone, into the Midian Stage; and, subsequently, (2) what criteria provide the means to recognize and trace this boundary. The situation with the upper boundary is more complex because of diverse approaches to its identification.

Lower boundary of the Midian Stage. As follows from data discussed above, all the Murgabian generic taxa, with a possible exception of *Praesumatrina*, are passing into the Midian Stage. Therefore, identifying the lower boundary of the latter by using fusulinids, we should take into account only the appearance of new genera. The Akasaka section, for instance, demon-

strates that the first occurrence of *Yabeina* and *Lepidolina* genera is confined to the *N. margaritae* Zone. Is this sufficient evidence for placing the boundary at the base of this zone? From the formal viewpoint, the answer is yes, because by definition the Midian Stage corresponds to the *Yabeina–Lepidolina* Genozone. However, such an answer would be more convincing, if a greater number of taxa in the fusulinid community showed their renewal.

To evaluate the situation from this standpoint, I shall try to analyze all changes in fusulinid biota from the basal beds of the *N. margaritae* Zone.

In addition to *Yabeina* and *Lepidolina*, the most characteristic Midian genera are *Dunbarula, Codonofusiella, Lantschichites, Reichelina, Sichotenella, Rauserella, Kahlerina, Metadoliolina, Sumatrina*, and *Chusenella*. Some of them, such as *Dunbarula, Codonofusiella, Sumatrina*, and *Chusenella*, appear in the Murgabian Stage, they are, however, not very characteristic of the latter. Other genera have never been reported from beds known to be Murgabian in age.

Unfortunately, fusulinid assemblages from the *N. margaritae* Zone of the Akasaka section are not very diverse, and as far as the aforementioned genera are concerned, the zone yielded here only *Codonofusiella* forms. Therefore, we shall consider fusulinids from other localities, which include beds traditionally correlated with the stratotype of the *N. margaritae* Zone.

In southern China, the *Yabeina* beds directly overlie the *Neoschwagerina* (after Sheng, 1963), or *Afghanella schencki* Zone (after Xiao *et al.*, 1986). The upper part of the latter yielded fusulinids typical of the *N. margaritae* Zone, which are represented by such characteristic species as *Neoschwagerina haydeni* Dutkevich et Khabakov, *Gifuella gifuensis* Honjo, *G. douvillei* (Ozawa), *Afghanella sumatrinaeformis* (Gubler), *Sumatrina longissima* Deprat, *S. fusiformis* Sheng, *S. annae* Volz, *Metadoliolina pulchra* (Sheng), and many others. *Kahlerina* sp., which was noted among them, does not occur in lower strata.

In the Salt Range, the *N. margaritae* Zone is thought to correspond to the lower beds 1 and 2 of the Wargal Formation, because the last bed yielded its index species (*Pakistan-Japanese ...*, 1985). Here and in bed 1, this species occurs together with *Codonofusiella* and *Reichelina* forms, typical fossils of the Midian Stage. The Midian age of these beds is also substantiated by the discoverey of conodonts of the *Hindeodus excavatus–Merrilina divergens* Zone, and these fossils suggest that the beds are correlative with the upper part of the Maokou Formation in southern China. Conodonts from overlying beds 4 and 5 belong to the *Hindeodus julfensis–Clarckina leveni* Zone of the Dzhulfian Stage[1] (Wardlaw and Pogue, 1995). The Murgabian Stage seems to be entirely missing in this section.

[1] H. Kozur (personal communication), who revised conodonts from the Wargal Formation, concluded that bed 4 still is of the Midian Stage, and indicative Dzhulfian taxa appear only in bed 5.

In the southeastern Pamirs, the Karasu Beds of the Gan Formation used to be considered as an equivalent of the *N. margaritae* Zone (Leven, 1967; Kotlyar *et al.*, 1983), although Miklukho-Maclay (1958) included them into the Murgabian Stage. The beds bear *Yabeina archaica* Dutkevich et Khabakov and highly evolved *Neoschwagerina* forms, such as *N.* ex gr. *margaritae* Deprat, *N. minoensis* Deprat, and *N. haydeni* Dutkevich et Khabakov. They are in association with *Dunbarula* spp. and *Codonofusiella* spp., both unknown from underlying deposits.

In the Khwaja-Ghar and Bulola localities of northern Afghanistan, the *N. margaritae* Zone is correlative with beds E and F of the carbonate group transgressively overlying limestones with fusulinids of the lower Murgabian Substage (Leven, 1982; Leven, in press). These beds enclose abundant fusulinids: *Dunbarula kitakamiensis* Choi, *Codonofusiella* sp., *Yangchienia haydeni* Thompson, *Kahlerina pachytheca* Kochansky-Devidé, *Pseudokahlerina compressa* Sosnina, *Colania* n. sp., *Neoschwagerina margaritae* Deprat, *N. haydeni* Dutkevich et Khabakov, *N. occidentalis* Kochansky-Devidé, *N. kojensis* Toumanskaya, *Afghanella tumida* Skinner et Wilde, *A. schencki* Thompson, *A. robbinsae* Skinner et Wilde, *A. sumatrinaeformis* (Gubler), *Sumatrina annae* Volz, *Verbeekina verbeeki* (Geinitz), *Pseudodoliolina ozawai* Yabe et Hanzawa, *Armenina crassispira* (Chen), *Chusenella minuta* Skinner, *C. sinensis* (Sheng), *Rugosochusenella* n. sp., *Rugosofusulina furoni* (Thompson), *Pseudofusulina paralpina* (Chen), *P. gigantea* (Deprat), *Eopolydiexodina afghanensis* (Thompson), and *E. bithynica* (Erk). Lys and Lapparent (1971) reported from these beds also *Reichelina minuta* Erk, *R. pulchra* K.M.-Maclay, and *R. cribroseptata* Erk (Lys and Lapparent, 1971). Such genera as *Reichelina, Kahlerina, Codonofusiella*, and *Dunbarula* indicate the Midian age of the beds. However, the rest of the assemblage is usually typical of the *N. margaritae* Zone of the Murgabian Stage. Nevertheless, the beds should be referred to the Midian Stage, because their *Neoschwagerina* forms are similar, or even identical, to respective species from localities in Turkey, Croatia, and Tunisia, where they occur in association with *Yabeina* species (Skinner, 1969; Kochansky-Devidé, 1965; Lys, 1988a; Vachard and Razgallah, 1993). In addition to *Yabeina* and *Neoschwagerina* genera, the described beds also yielded most of the taxa listed above.

A similar fusulinid assemblage, though lacking yabeins and therefore considered as Murgabian (Siehl, 1967; Vachard, 1980), is known from limestones exposed at the Altimur Pass southward of Kabul. From these rocks, I identified *Dunbarula nana* Kochansky-Devidé, *Lantschichites minimus* (Chen), *Yangchienia thompsoni* Skinner et Wilde, *Kahlerina pachytheca pusilla* Kochansky-Devidé, *K. globiformis* Sosnina, *K. africana* Skinner et Wilde, *Nankinella* sp., *Sphaerulina croatica* Kochansky-Devidé, *Reichelina* cf. *changhsingensis* Sheng et Chang, *Colania* sp.,

Neoschwagerina margaritae Deprat, *N. haydeni* Dutkevich et Khabakov, *Verbeekina* (*Verbeekina*) *verbeeki* (Geinitz), *V.* (*Paraverbeekina*) *pontica* A.M.-Maclay, *V.* (*Quasiverbeekina*) n. sp., *Pseudofusulina hupehensis* (Chen), *P. solita* (Skinner), and *Rugososchwagerina* n. sp.

Lantschichites, Kahlerina, and *Reichelina* forms from this assemblage definitely indicate its Midian age. This conclusion is confirmed, because limestones immediately overlying this level contain the typical Dzhulfian fusulinids, among which *Lantschichites, Codonofusiella, Reichelina, Colaniella, Robuloides*, and some other taxa were identified by A. Ziehl and D. Vachard.

Localities of the Velebit and Lika ranges in Croatia, which were described by Kochansky-Devidé (1965), are also very significant for the analysis in question. Here, the beds ("second and third limestone zones") bearing *Yabeina syrtalis* (Douville) are doubtlessly of the Midian age. Light dolomites below them yielded *Neoschwagerina rotunda* Deprat, *N. craticulifera* (Schwager), *N. occidentalis* Kochansky-Devidé, and *N. margaritae* Deprat, which are very similar to the species from Afghanistan. Moreover, in both regions these taxa associate with *Dunbarula, Kahlerina, Verbeekina, Sphaerulina*, and *Nankinella* forms. All these taxa, including genus *Neoschwagerina*, proceed into the *Yabeina* Beds.

A similar situation was observed in Tunisia, where distinct beds with *Yabeina syrtalis* (Douville) and *Y. punica* (Douville) also yielded highly evolved species of *Neoschwagerina, Kahlerina, Reichelina, Rauserella, Codonofusiella, Dunbarula*, and *Chusenella* genera (Skinner and Wilde, 1967; Vachard and Razgallah, 1993). This fusulinid assemblage is definitely Midian in general composition, and I cannot agree with Vachard and Razgallah, who referred it, though with reservations, to the Murgabian Stage based on the presence of *Neoschwagerina* forms. As was shown, this genus is transient throughout the Midian interval up to the *M. lepida–L. kumaensis* Beds.

Well-founded data by Lys (1988b), which are based on drilling results, allowed him to show that deposits transgressively overlying the Lower Permian strata contain fusulinids of the *N. margaritae* Zone and beds transitional between this and *N. craticulifera* Zone. From the upper part of this interval, he identified *Rauserella staffi* Skinner et Wilde, *Reichelina cribroseptata* Erk, *Codonofusiella nana* Erk, *C. paradoxica* Dunbar et Skinner (= *Lantschichites*?), *Dunbarula mathieui* Ciry, *D. nana* Kochansky-Devidé, *Yangchienia thompsoni* Skinner et Wilde, *Chusenella rabatei* Skinner et Wilde, *Pseudofusulina navillei* (Erk), *Eopolydiexodina afghanensis* (Thompson), *E. bithynica* (Erk), *E. megasphaerica* (Leven), *Neoschwagerina fusiformis* Skinner et Wilde, *N. tebagensis* Skinner et Wilde, and *Sumatrina annae* Volz. Somewhat lower, this scientist recorded *Codonofusiella nana* Erk, *Dunbarula nana* Kochansky-Devidé, *Leella bellula* Skinner et Wilde, *Rugososchwagerina sera* (Erk), *Afghanella africana* Skinner et Wilde, *A. robbinsae* Skinner et Wilde, *A. tumida* Skinner et Wilde, *Sumatrina longissima* Deprat, *Verbeekina* (*Paraverbeekina*) *pontica* A.M.-Maclay, and *V.* (*Verbeekina*) *verbeeki* (Geinitz).

In total, this fusulinid assemblage is identical to that from Afghanistan and similarly includes typical smaller and aberrant fusulinids of the Midian Stage.

Fusulinids, which were discovered from exotic blocks in Sicily (Skinner and Wilde, 1966), can be attributed to the same assemblage. Present among them are highly evolved representatives of *Neoschwagerina, Verbeekina, Chusenella, Rugososchwagerina, Yangchienia*, and some other taxa, as well as *Kahlerina, Dunbarula*, and *Rauserella* species. These fusulinids associate with ammonoids of the so-called "Sicilian Assemblage" (Gemmellaro, 1887). It is also interesting that similar ammonoids were recorded in the Cache Creek Group of British Columbia, where they occur together with primitive *Yabeina* forms (Ross, 1971). These data provide additional grounds to correlate strata bearing this fauna with the *N. margaritae* Zone in its stratotype.

This information shows that in the central and western Tethys fusulinid assemblages experienced renewal with the appearance of many Midian genera before the emergence of *Yabeina* forms in the beds, which used to be correlated with *N. margaritae* Zone. The changes are notable not only among fusulinids, but also in assemblages of smaller foraminifers, which incorporated at that time such genera as *Dagmarita, Baisalina, Hemigordiopsis, Frondina, Abadehella, Neoendothyra, Rectostipulina*, and some others typical of the Midian Stage (Lys, 1988b; Altiner, 1984). The evident reason of this renewal was the marine transgression over the Tethyan region, most noticeable in its peri-Gondwana areas (Lys, 1988a, 1988b; Baud *et al.*, 1993; Leven, 1993a, 1993b). As is clear from many sections (Tunisia, Oman, Croatia, Turkey, and Iran), the beginning of the transgression was confined to the time of the *N. margaritae* Zone.

To summarize the discussion, it is possible to conclude the following:

(1) In the eastern Tethys, the first occurrence level of *Yabeina* and *Lepidolina* genera is confined to the *N. margaritae* Zone in its stratotype section.

(2) In more western areas, *Yabeina* forms appear later, however the beds correlative with the *N. margaritae* Zone of Japan enclose here other genera typical of the Midian Stage. Some of them are transient and occur even higher in the sequence, in the Dzhulfian and Dorashamian stages. A similar situation is also characteristic of smaller foraminifers.

(3) The renewal of foraminiferal assemblages was related to a wide transgression.

(4) Both the abiotic and biotic events were more significant at the beginning than at the end of the *N. margaritae* interval. Therefore, the base of this zone seems to represent the preferable level for the lower boundary of the Midian Stage.

(5) This model of the boundary position does not suggest a revision of the original concept identifying the Midian Stage as a unit corresponding to the *Yabeina–Lepidolina* Genozone, because these genera first appear at the base of the *N. margaritae* Zone in its stratotype locality. The zone base is also marked by first occurrences of many other index genera of the Midian Stage listed in its initial definition.

(6) The model is in good agreement with data on the stage stratotype corresponding to the Permian stratigraphic range of the Arpa and Khachik formations in Transcaucasia. Actually, remains of *Yangchienia thompsoni, Sumatrina annae, Verbeekina, Chusenella, Pseudofusulina,* and first species of *Kahlerina, Minojapanella* (*Wutuella*), *Codonofusiella, Dunbarula*, and *Reichelina* genera are confined to the base of the Arpa Formation. The same level yielded here typical taxa of smaller foraminifers of the Midian Stage, such as *Abadehella, Neoendothyra, Dagmarita, Pseudolangella*, and *Partisania* (Leven, 1975b; Kotlyar *et al.*, 1989). All of these genera and species are also characteristic of beds referred to the *N. margaritae* Zone.

(7) Fusulinids do not provide a unique criterion to place and trace the Murgabian-Midian boundary, regardless of its definition. One may speculate only on a series of interchangeable indicators, among which are the following: the first occurrence (in general, but not in a particular section) of *Yabeina* and *Lepidolina* taxa; the appearance of *Afghanella* species corresponding to the evolutionary level of *Afghanella robbinsae* and *A. tumida*; the emergence of *Sumatrina* forms of *S. annae* and *S. fusiformis* type; the origin of evolved *Neoschwagerina* species such as *N. haydeni* (s.s.), *N. craticulifera* (s.s.), and *N. occidentalis*; and finally, the first occurring representatives of *Kahlerina, Reichelina, Sichotenella*, and *Lantschichites* genera.

All these features mark the lower boundary of the Midian Stage, if it corresponds to the base of the *N. margaritae* Zone. At present, it is difficult to suggest the limitotype for this version of the boundary position. Sections of southern China are most promising in this respect. In the case of a higher position, the boundary becomes less expressive and is marked by changes at species level only.

It should be stressed that the Midian Stage was distinguished as a part of the former Murgabian Stage. It is the part that was inadequately studied by Miklukho-Maclay. Therefore, in the current stratigraphic scale, the Murgabian Stage is smaller in range than the original, insufficiently substantiated unit. According to formal principles of stratigraphic nomenclature, it seems to be more correct to identify the rest of the former Murgabian Stage (below the Midian interval) under the new stage name. However, at the proper time, this principle was left unsatisfied, and now it would be unreasonable to change anything, because the name of Murgabian Stage is widely used as applied to *Neoschwagerina* Beds underlying strata with *Yabeina* and *Lepidolina* species.

Upper boundary of the Midian Stage. Upon first examination of the Midian Stage in the type sections of Transcaucasia, this boundary was placed at the base of the *Araxoceras latum* Zone including the beds bearing brachiopods of *Araxilevis* genus (Leven, 1980). This boundary position corresponded to the originally defined lower boundary of the Dzhulfian Stage, which was fixed at the base of ammonite (*"Prototoceras"*) beds in the Dzhulfa locality (Schenck *et al.*, 1941). In the later publication (*Evolyutsiya ...*, 1965), this boundary was interpreted somewhat differently. It was lowered down to the base of the so-called *Codonofusiella* (Chanahchi) Beds, because all *Schwagerina* and *Neoschwagerina* forms disappear at this level. Recently, this viewpoint was supported by Kotlyar *et al.* (1989), and their arguments remain the same. In addition, it was noted that the Chanahchi Beds are distinct because of first appearing *Araxilevis* species and first ammonoids from the Araxoceratidae family. The cited authors also argued that this position of the boundary corresponds to the boundary level between the Maokou and Wuchiaping formations in southern China, which again marks the disappearance level of schwagerinids and neoschwagerinids, and the first occurrence of araxoceratids.

In recent years, there have been attempts to solve this problem by using conodonts. According to Kozur *et al.* (1978), the Midian-Dzhulfian boundary is, in its original definition, almost identical to the base of the *Clarkina leveni* Zone, which is well traceable in many Tethyan sections. In southern China, this level is in the middle of the Wuchiaping Formation, and Chinese scientists are in favor of distinguishing the Wuchiapingian Stage, which is of greater stratigraphic range, instead of the Dzhulfian Stage, and they place its lower boundary at the base of the *Clarkina postbitteri* Zone (Jin Yugan *et al.*, 1994a, 1994b). However, the conodont taxonomy and zonation for the Permian interval in question are thus far insufficiently elaborated, as is evident from a series of publications (Jin Yugan *et al.*, 1994a, 1994b; Kozur, 1994; Mei Shilong *et al.*, 1994). Therefore, using data on conodonts alone, it is preferable to rely on the base of the *C. leveni* Zone, which is well traceable and adequately understood.

Problems concerning the boundary between the Midian and Dzhulfian stages arise due to fact that it was originally defined either by data on fusulinids, as in the first instance, or by the ammonoid succession, as in the second. Because of their different facial control, these faunal groups are inappropriate for obtaining a definite answer to the question: what event in the evolution of ammonoids (brachiopods and conodonts as well) corre-

Table 3. Position of the *L. kumaensis* Zone in different correlation schemes

Ammonoids	Conodonts	Kotlyar *et al.* (1989)	Kotlyar *et al.* (1983)	Toriyama (1973)
Araxoceras	*C. leveni*			*L. k.*
Eoaraxoceras *Roadoceras*	*C. assimetrica* *C. dukouensis* *C. postbitteri*		*L. k.*	
Timorites	*M. granti* *M. xuanhanensis* *M. praexuanhan* *M. altudaensis*	*L. k.*		

sponded to the mass extinction of schwagerinids and neoschwagerinids, which marks the upper boundary of the Midian Stage? In other words, what is the interval in the ammonite and conodont zonations equivalent to the *L. kumaensis* Zone, the uppermost in the stage? There are several opinions concerning this problem (Table 3).

Most of the arguments in favor of one or another solution are indirect, controversial, and not very convincing. Only three schemes considering relations between the *L. kumaensis*, conodont and ammonoid zones are sufficiently concrete.

One of them has already been mentioned in the description of the *L. kumaensis* Zone. It is based on the sequence in the Sichuan Province of China studied by Rui Lin (1983). His find of *L. kumaensis* species in the middle part of the Maokou Formation allowed him to conclude that the pertinent zone corresponds to the entire upper portion of the formation. This was the reason to suggest a higher position of the *C. postbitteri, C. dukouensis*, and *C. assimetrica* conodont zones, which were recognized in basal strata of the Wuchiaping Formation and correlated with the *Codonofusiella* (Chanahchi) Beds in Transcaucasia.

Kotlyar (1994) used these data to substantiate the range of the *L. kumaensis* Zone in the Tethyan scale. As was mentioned, however, paleontologic determinations by Rui Lin are incorrect. The forms that he described are more primitive than *L. kumaensis*, and their host rocks are hardly younger than the lower Midian strata. This conclusion does not contradict the data on fusulinids discovered from the upper 100 m of the sequence and dated as merely Midian in age. As for the *L. kumaensis* Zone proper, it is equally possible that it corresponds to either the uppermost strata of the Maokou Formation, or to basal beds of the Wuchiaping Formation, and may even be missing in the section, because the latter formation overlies the former with a distinct unconformity.

The next fact, which was used by Kotlyar to substantiate the pre-Wuchiapingian age of the *L. kumaensis* Zone, is the occurrence of conodonts *Mesogondolella postserrata, Clarkina bitteri, C. rosenkrantzi, C. denticulata,* and *C. wilcoxi* in association with the index fusulinid assemblage in the upper part of the Chandalaz Horizon in Primor'e. However, only the first of the listed conodont species is definitely pre-Wuchiapingian in age. *C. bitteri* shows a wide stratigraphic range up to the *C. leveni* Zone. According to Kozur (1994), the upper part of the last zone also yielded *C. rosenkrantzi*, although this form appears to be older in origin. Wardlaw and Mei Shilong (1994) reported that the first occurrence level of *C. wilcoxi* is at the base of the *Merrilina divergens* Zone distinguished near the top of the Word Formation in Texas, although in Kozur's opinion this zone corresponds to the lower part of the *C. leveni* Zone. This controversial dating of conodont assemblages does not provide grounds for conclusive inferences, and only additional data can clarify the problem.

Relations between the *L. kumaensis* and ammonite zones can be discussed using available data on the Kitakami localities in Japan. The *L. kumaensis* Beds were distinguished here in the upper part of the Iwaizaki Limestone (Ishii *et al.*, 1975). The overlying Toyoma Formation yielded ammonoids including the *Araxoceras* forms, which are typical of the lower half of the Dzhulfian (s.s.) Stage. Other recovered genera (*Prototoceras, Stacheoceras*, and *Cyclolobus*) may occur in the Dzhulfian and somewhat older strata. These data allow us to speak definitively only about pre-Dzhulfian age of the *L. kumaensis* Beds, if this stage begins with the *Araxoceras* Zone. Furthermore, these beds may correspond to either the ammonite zones distinguished in lower strata of the Wuchiaping Formation in China, or to somewhat older units. It is also necessary to bear in mind that geological relations between beds bearing fusulinids and ammonoids are not very clear in this locality, and it is not inconceivable that they are of tectonic origin.

The unbiased consideration of the above data shows that the pre-Wuchiapingian age of the *L. kumaensis* Zone can be accepted without reservation. They also allow it to be correlated with the lower part of the Wuchiaping Formation in China and *Codonofusiella* Beds in Transcaucasia. In this regard we should note the recent information (Jin Yugan *et al.*, 1994a; Wardlaw and Pogue, 1995) on typically Dzhulfian conodonts from the Kalabagh Beds of the Wargal Formation, which are usually considered on the basis of brachiopods and smaller foraminifers to be an equivalent of the *L. kumaensis* Zone. If these data are validated, then the range of this zone may be regarded in accordance with Toriyama's idea (Toriyama, 1973) as comprising not only the lower, but also the middle part of the Wuchiaping Formation, which is the stratigraphic analogue of the *Araxoceras latum* Zone of the Dzhulfian Stage in Transcaucasia.

Evaluating all the data concerning the upper boundary of the Midian Stage, I came to the following conclusions:

(1) The fusulinid succession does not permit the *L. kumaensis* Zone to be disassociated from underlying deposits, and this zone should be considered as a constituent of the Midian Stage.

(2) Accordingly, the upper stage boundary must be placed at the top of the zone. It may correspond to the base of the *Codonofusiella* Beds in Transcaucasia, and to lower boundaries of the Wuchiaping Formation and ammonoid *Araxoceras*, or conodont *C. leveni* zones in China depending on the expected data on the position of *L. kumaensis* Zone in the accepted ammonoid and conodont zonations. Prior to this, the boundary should be left at the level accredited by the ISC, i.e., at the base of the *Araxoceras* Zone. The earlier disappearance of schwagerinids and neoschwagerinids in some sequences, for instance in type sections of Transcaucasia, may be related to relevant facial conditions.

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REFERENCES

Altiner, D., Upper Permian Foraminiferal Biostratigraphy in Some Localities of the Taurus Belt, *Geology of the Taurus Belt, Int. Symp., September 26–29, Ankara, Turkey*, Tekeli, O. and Goncuoglu, C., Eds., Ankara: MTA, 1984, pp. 255–268.

Baud, A., Marcoux, J., Guiraud, R., Ricou, L.-E., and Gaetani, M., Late Murgabian (266–264 Ma), in *Atlas Tethys Palaeoenvironmental Maps*, Dercourt, J., Ricou, L.L., and Vrielynck, B., Eds., Paris, 1993, pp. 1–12.

Deprat, J., Étude des Fusulinidés de Chine et d'Indochine et classification des calcaires à fusulines (2 memoire): Les Fusulinidés des carboniériens et permiens du Tonkin, du Laos et du Nord Annam, *Mem. Serv. Geol. Indochine*, 1913, vol. 2, no. 1, pp. 1–74.

Deprat, J., Étude des Fusulinidés de Chine et d'Indochine et classification des calcaires à fusulines (3 memoire): Étude comparative des Fusulinidés d'Akasaka (Japan) et des Fusulinidés de Chine et d'Indochine, *Mem. Serv. Geol. Indochine*, 1913, vol. 3, no. 1, pp. 1–45.

Dutkevich, G.A., New *Yabeina* Species from the Upper Permian Deposits of Southeastern Pamirs, *Paleontol. Zh.*, 1967, no. 1, pp. 18–21.

Gemmellaro, G.G., La fauna dei calcari con Fusulina della valle del fiume Sosio (nella provincia di Palermo), *Giorn. Sci. Natur. Econ.*, 1887, vol. 19, pp. 1–106.

Hanzawa, S. and Murata, M., The Paleontological and Stratigraphical Considerations on the Neoschwagerininae and Verbeekininae with the Description of Some Fusulinid Foraminifera from the Kitakami Massif, Japan, *Sci. Rep. Tohoku Univ. (Geol.)*, 1963, vol. 35, pp. 1–31.

Honjo, S., Neoschwagerinids from the Akasaka Limestone (A Paleontological Study of the Akasaka Limestone, 1st Report), *J. Fac. Sci., Hokkaido Univ.*, 1959, vol. 10, no. 1, pp. 11–161.

Ingavat, R., Toriyama, R., and Pitakpaivan, K., Fusuline Zonation and Faunal Characteristics of the Ratburi Limestone in Thailand and Its Equivalents in Malaysia, in *Geology and Paleontology of S. Asia, Symp.: Tsukuba'78*, 1980, Univ. Tokyo, pp. 43–62.

Iranian-Japanese Research Group, The Permian and the Lower Triassic Systems in Abadeh Region, Central Iran, *Mem. Fac. Sci., Kyoto Univ., Ser. Geol. Mineral.*, 1981, vol. 47, no. 2, pp. 61–133.

Ishii, K., On Some Fusulinids and Other Foraminifera from the Permian of Pahang, Malaya, *J. Geosci., Osaka City Univ.*, 1966, vol. 9, art. 4-V, pp. 131–142.

Ishii, K., Kato, M., and Nakamura, K., Permian Limestones of West Cambodia: Lithofacies and Biofacies, *Spec. Pap. Paleont. Soc. Japan*, 1969, no. 14, pp. 41–55.

Ishii, K., Okimura, Y., and Nakazawa, K., On the Genus *Colaniella* and Its Biostratigraphic Significance, *J. Geosci., Osaka City Univ.*, 1975, vol. 19, art. 6, pp. 107–129.

Jin Yugan, Glenister, B.F., Kotlyar, G.V., and Sheng Jinzhang, An Operational Scheme of Permian Chronostratigraphy, in *Palaeoworld 4*, Nanjing Univ., 1994a, vol. 1, pp. 1–13.

Jin Yugan, Zhu Zili, and Mei Shilong, The Maokouan–Lopingian Boundary Sequence in South China, in *Palaeoworld 4*, Nanjing Univ., 1994b, vol. 1, pp. 138–152.

Kobayashi, F., Middle Permian Foraminifers of the Gozeniyama Formation, Southern Kwanto Mountains, Japan, *Bull. Nat. Sci. Mus., Ser. C: Geol.* (Tokyo), 1986, vol. 12, no. 4, pp. 131–163.

Kochansky-Devidé, V., Die Fusuliniden Foraminiferen aus dem Karbon und Perm im Velebit und der Lika (Kroatien). Mittleres und Oberes Perm, *Jugoslav. Acad. Zn. i Um., Acta Geol.*, 1965, vol. 5, pp. 101–148.

Kotlyar, G.V., The *Lepidolina kumaensis* Zone and its Position in the Tethyan Stratigraphic Scale, *Permophiles. A Newsletter of SCPS*, 1994, no. 24, pp. 26–28.

Kotlyar, G.V., Zakharov, Yu.D., Kochirkevich, B.V., *et al.*, *Pozdnepermskii etap evolutsii organicheskogo mira. Dzhul'finskii i dorashamskii yarusy SSSR* (Late Permian Stage in Evolution of Organic World. Dzhulfian and Dorashamian Stages in the USSR), Leningrad: Nauka, 1983.

Kotlyar, G.V., Zakharov, Yu.D., Kropacheva, G.S., *et al.*, *Pozdnepermskii etap evolutsii organicheskogo mira. Midiiskii yarus SSSR* (Late Permian Stage in Evolution of Organic World. Midian Stage in the USSR), Leningrad: Nauka, 1989.

Kozur, H., Permian Pelagic and Shallow-Water Conodont Zonation, *Permophiles. A Newsletter of SCPS*, 1994, no. 24, pp. 16–20.

Kozur, H., Leven, E.Ya., Lozovskii, V.R., and Pyatakova, M.V., Subdivision of Permian–Triassic Boundary Beds in Transcaucasia Based on Conodonts, *Byull. Mosk. O-va. Ispyt. Prir., Otd. Geol.*, 1978, vol. 53, no. 5, pp. 15–24.

Leven, E.Ya., On Phylogeny of Higher Fusulinids and Subdivision of Upper Permian Deposits in Tethyan Regions, *Vopr. Mikropaleontol.*, 1963, no. 7, pp. 57–70.

Leven, E.Ya., *Stratigrafiya i fuzulinidy permskikh otlozhenii Pamira* (Stratigraphy and Fusulinids from Permian Deposits of Pamirs), Moscow: Nauka, 1967.

Leven, E.Ya., Scale of Permian Stages for Tethyan Deposits, *Byull. Mosk. O-va. Ispyt. Prir., Otd. Geol.*, 1975a, vol. 50, no. 1, pp. 5–21.

Leven, E.Ya., Stratigraphy of Permian Deposits in Transcaucasia, *Sov. Geol.*, 1975b, no. 1, pp. 96–100.

Leven, E.Ya., *Ob'yasnitel'naya zapiska k stratigraficheskoi shkale permskikh otlozhenii oblasti Tetis* (Explanatory Notes for the Stratigraphic Scale of Permian Deposits in Tethyan Regions), Leningrad: Vses. Geol. Inst., 1980.

Leven, E.Ya., Genus *Cancellina* Hayden and Its Position in the System of Higher Fusulinids, *Vopr. Mikropaleontol.*, 1982, no. 25, pp. 40–51.

Leven, E.Ya., Main Events of Tethyan Permian History and Fusulinids, *Permophiles. A Newsletter of SCPS*, 1992, no. 20, pp. 23–25.

Leven, E.Ya., Main Events in Permian History of the Tethys and Fusulinids, *Stratigr. Geol. Korrelyatsiya*, 1993a, vol. 1, no. 1, pp. 59–75.

Leven, E.Ya., Phylogeny of Sumatrinids and Problems of Biozonation in the Murgabian and Midian Stages of the Permian, *Paleontol. Zh.*, 1993b, no. 3, pp. 23–29.

Leven, E.Ya., Permian of Afghanistan (Stratigraphy and Fusulinids), *Spec. Pap. Geol. Soc. Am.* (in press).

Lys, M., Biostratigraphie du Carbonifere et du Permien en Mesogee (Espagne, Afrique du Nord, Regions Egeennes, Proche-Orient). Etudes micropaleontologiques (Foraminiféres), paleobiogeographie, *Thése*, Univ. de Paris Sud, Centre d'Orsay, 1988a.

Lys, M., Carboniferous and Permian Marine Deposits in Southern Tunisia—Micropaleontology (Foraminifera) and Paleobiogeography, *Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine*, 1988b, vol. 12, no. 2, pp. 601–659.

Lys, M. and Lapparent, A.F., Foraminiféres microphacies du Permien de l'Afghanistan Central, *Notes et Mem. sur le Moyen-Orient*, 1971, vol. 12, pt. 1, pp. 49–133.

Mei Shilong, Jin Yugan, and Wardlaw, B.R., Zonation of Conodonts from the Maokouan-Wuchiapingian Boundary Strata, South China, in *Palaeoworld 4*, Nanjing Univ., 1994, vol. 1, pp. 225–233.

Miklukho-Maclay, A.D., Stage Subdivisions of Marine Permian Deposits in the Southern USSR, *Dokl. Akad. Nauk SSSR*, 1958, vol. 120, no. 1, pp. 175–178.

Miklukho-Maclay, A.D., *Verkhnii paleozoi Srednei Asii* (Upper Paleozoic in the Central Asia), Leningrad: Len. Gos. Univ., 1963.

Morikawa, R., Fusulinids from the Akasaka Limestone (Part 1), *Sci. Rep. Saitama Univ., Ser. B*, 1958, vol. 31, no. 1, pp. 93–130.

Morikawa, R. and Suzuki, S., Fusulinids from the Akasaka Limestone (Part 2), *Sci. Rep. Saitama Univ., Ser. B*, 1961, vol. 4, no. 1, pp. 43–74.

Nakazawa, K., Correlation of the Marine Upper Permian of Tethys, *in XI-e Congrés International de Stratigraphie et de Geologie du Carbonifére. Beijing, 1987. Compte Rendu 2*, Nanjing, 1989, pp. 229–234.

Nakazawa, K., Kapoor, H.M., Ishii, K., Bando, Y., Okimura, Y., and Takuoka, T., The Upper Permian and Lower Triassic in Kashmir, India, *Mem. Fac. Sci., Kyoto Univ. (Geol., Mineral.)*, 1975, vol. 42, no. 1, pp. 1–106.

Nogami, Y., Permische Fusuliniden aus dem Atetsu-Plateau Sudwest Japans. Teil 1, *Mem. Coll. Sci., Kyoto Univ. (Geol., Mineral.), Ser B*, 1961, vol. 28, no. 2, pp. 159–249.

Nogami, Y., Permische Fusuliniden aus dem Atetsu-Plateau Sudwest Japans. Teil 2, *Mem. Coll. Sci., Kyoto Univ., (Geol., Mineral.), Ser B*, 1961, vol. 27, no. 3, pp. 159–243.

Ozawa, T., Evolution of *Lepidolina multiseptata* (Permian Foraminifer) in East Asia, *Mem. Fac. Sci., Kyushu Univ., Ser. D: Geol.*, 1975, vol. 23, no. 2, pp. 117–164.

Ozawa, T., Notes on Phylogeny and Classification of the Superfamily Verbeekinoidea, *Mem. Fac. Sci., Kyushu Univ., Ser. D: Geol.*, 1970, vol. 20, no. 1, pp. 17–58.

Ozawa, Y., Stratigraphical Studies of the Fusuline Limestone of Akasaka, Province of Mino, *J. Coll. Sci., Imper. Univ. Tokyo*, 1927, vol. 2, no. 3, pp. 121–164.

Pakistan-Japanese Research Group, Permian and Triassic Systems in the Salt Range and Surghar Range, *The Tethys*, Nakazawa, K. and Dickins, J.M., Eds., Tokai Univ., 1985, pp. 221–317.

Postanovleniya Mezhvedomstvennogo stratigraficheskogo komiteta i ego postoyannykh komissii (Resolutions of the Interdepartmental Stratigraphic Committee and Its Commissions. Issue 19), Leningrad: Vses. Geol. Inst., 1981, no. 19, pp. 50–52.

Razvitie i smena morskikh organizmov na rubezhe paleozoya i mezozoya (Evolution and Succession of Marine Organisms across the Paleozoic–Mesozoic Boundary), Moscow: Nauka, 1965.

Ross, Ch.A., New Species of *Schwagerina* and *Yabeina* (Fusulinacea) of Wordian Age (Permian) from Northwestern British Columbia, in *GSC Bull. 197: Contributions to Canadian Paleontology Published by Department of Energy, Mines and Resources*, Ottawa: 1971, pp. 95–106.

Rui Lin, On the *Lepidolina kumaensis* Fusulinacean Fauna, *Bull. Nanjing Inst. Geol. Paleontol., Acad. Sinica*, 1983, no. 6, pp. 249–270.

Schenck, H., Hedberg, C., Tomplinson, J., Euton, L., and White, R., Stratigraphic Nomenclature, *Bull. Am. Assoc. Petrol. Geol.*, 1941, no. 225, pp. 2195–2211.

Sheng, J.S., Permian Fusulinids of Kwangsi, Kueichow and Szechuan, *Paleontol. Scinica, N.S.B.*, 1963, vol. 149, no. 10, pp. 1–247.

Sheng, J.S. and Jin Yugan, Correlation of Permian Deposits in China, in *Palaeoworld 4*, Nanjing Univ., 1994, vol. 1, pp. 14–113.

Skinner, J.W., Permian Foraminifera from Turkey, *Univ. Kansas Paleontol. Contrib.*, 1969, pap. 36, pp. 1–14.

Skinner, J.W. and Wilde, G.L., Permian Foraminifera from Tunisia, *Univ. Kansas Paleontol. Contrib.*, 1967, pap. 30, pp. 1–22.

Skinner, J.W. and Wilde, G.L., Permian Fusulinids from Sicily, *Univ. Kansas Paleontol. Contrib.*, 1966, pap. 8, pp. 1–16.

Tien, N.D., Étude micropaleontologique (Foraminiféres) de matériaux du Permien du Cambodge, *Thése*, Univ. de Paris Sud, Centre d'Orsay, 1979.

Toriyama, R., Geology of Akiyoshi, Part 1, *Mem. Fac. Sci., Kyushu Univ., Ser D: Geol.*, 1954, vol. 4, no. 1, pp. 29–97.

Toriyama, R., Geology of Akiyoshi, Part 3: Fusulinids of Akiyoshi, *Mem. Fac. Sci., Kyushu Univ., Ser D: Geol.*, 1958, vol. 7, no. 7, pp. 1–276.

Toriyama, R., Summary of the Fusuline Faunas in Thailand and Malaysia, *Geol. Paleontol. Southeast Asia*, Kobayashi, T., Toriyama, R., and Hashimoto, W., Eds., 1984, vol. 25, pp. 137–146.

Toriyama, R., Upper Permian Fusulinan Zones, *Mem. Canad. Soc. Petrol. Geol.*, 1973. no. 2, pp. 498–512.

Toriyama, R., Hamada, T., Igo, H., *et al.*, The Carboniferous and Permian Systems in Thailand and Malaysia, *Geol. Paleontol. Southeast Asia*, Kobayashi, T. and Toriyama, R., Eds., 1975, vol. 15, pp. 39–75.

Vachard, D., Tethys et Gondwana au Paleozoique Supérieur les donnes Afghanes, *Docum. et Trav. IGAL, Paris*, 1980, no. 2, pp. 1–463.

Vachard, D. and Ferriére, J., Une association a *Yabeina* (Foraminifére Fusulinoide) dans le Midien (Permien supérieur) de la région de Whangoroa (Baie d'Orua, Nouvelle-Zélande), *Rev. Micropaléontol.*, 1991, vol. 34, no. 3, pp. 201–230.

Vachard, D. and Razgallah, S., Discussion sur l'age Murgabien ou Midien des series Permiennes du Jebel Tebaga (Sud de la Tunisue), *Riv. Ital. Paleont. Strat.*, 1993, vol. 99, no. 3, pp. 327–356.

Wardlaw, B.R. and Mei Shilong, Succession of Conodont Zones from the Permian "Kuhfeng" Formation, Xuanhan, Sichuan, and Its Implication in Global Correlation, *Acta Paleontol. Sinica*, 1994, vol. 33, no. 1, pp. 1–23.

Wardlaw, B.R. and Pogue, K.R., The Permian of Pakistan, in *The Permian of Northern Pangea*, Scholle, P.A., Peryt, T.M., and Ulmer, D.S., Eds., Berlin, 1995, pp. 215–224.

Xiao, W., Zhang, L., Wang, H., and Dong, W., *Early Permian Stratigraphy and Faunas in Southern Guizhou*, Guizhou: Peoples Publ. House, 1986.

Zhang Zugi, The Permian System in South China, *Newslett. Stratig.*, 1984, vol. 13, no. 3, pp. 156–174.

Ziehl, A., Zur Stratigraphie und Palaeogeographie des Perm in Afghanistan, *Geol. Rundsch.*, 1967, vol. 56, no. 3, pp. 795–818.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 552–566. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 32–46.
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The Paleogene of the Utkholok Peninsula, Western Kamchatka

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Abstract—The paper deals with the foraminifer and fossil plant biostratigraphy of heterotopic (marine, continental, volcanogenic) Paleogene sequences of the Utkholok Peninsula situated in the Tigil' stratotype region of Western Kamchatka. The Zubchatyi Mys Formation was found to comprise heterochronous (Maastrichtian, upper Eocene) deposits. The discordant (with a hiatus), interrelationship between volcanics and the overlying continental sequence is shown. Paleontological data also suggest hiatuses between the Cretaceous and Paleogene (Ovra Cape, Uvuch Mount) and in the late Paleocene–middle Eocene interval (Uvuch Mount). The invalidity of the Uleven Group is shown, as, according to paleobotanic data, its lower part (the Zubchatyi Mys Formation) is younger (the late Eocene) than the upper Sosopkhan Formation (the early Paleocene). The "Danian" plant assemblage from the Zubchatyi Mys Formation stratotype is incompatible with the standard scheme of Western Kamchatka due to its late Eocene age.

Key words: *foraminifers, flora, biostratigraphy, Paleogene, Western Kamchatka.*

One of the principal current problems of the Paleogene stratigraphy of Western Kamchatka is related to sections of the Utkholok Peninsula and the adjacent Snatol River basin. The problem is what local and regional (standard) units should be used for stratigraphic schemes in the Tigil' stratotype region, the units adopted at the 2nd Interdepartmental Stratigraphic Conference in Petropavlovsk-Kamchatskii of 1974, such as the Khungul, Napan, Snatol formations and horizons of the same names of the Tigil' Group and the Kovachina Horizon of the Kovachina Group (*Reshe-niya...*, 1982) or the scheme suggested by Klenov (1961) and comprising the Khulgun and Pkhyn formations of the Uleven Group and the Snatol and Kovachina formations of the Kamakveem Group. The first scheme follows the concept of the continuous sedimentation in the Paleogene, whereas the second one assumes the existence of a major break in the Paleogene sequence. At present, Klenov's views are accepted with some modifications by a group of researchers (Gladenkov *et al.*, 1985, 1989; *Eotsen* ..., 1991).

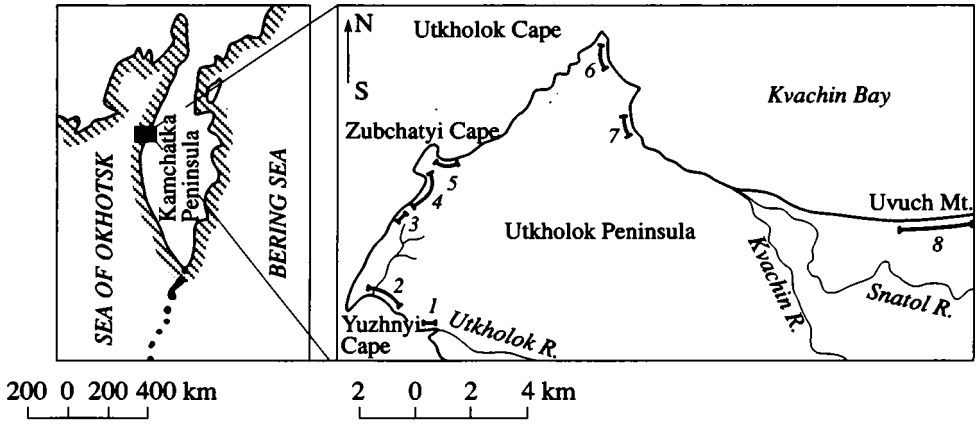

Fig. 1. Location of principal sections in the Utkholok Peninsula.
(*1*) Utkholok River mouth; (*2*) Yuzhnyi Cape–Utkholok River mouth; (*3*) 5 to 6 km south of the Zubchatyi Cape; (*4*) a bay south of the Zubchatyi Cape; (*5*) a bay north of the Zubchatyi Cape; (*6*) Utkholok Cape; (*7*) Ovra Cape; (*8*) Uvuch Mount.

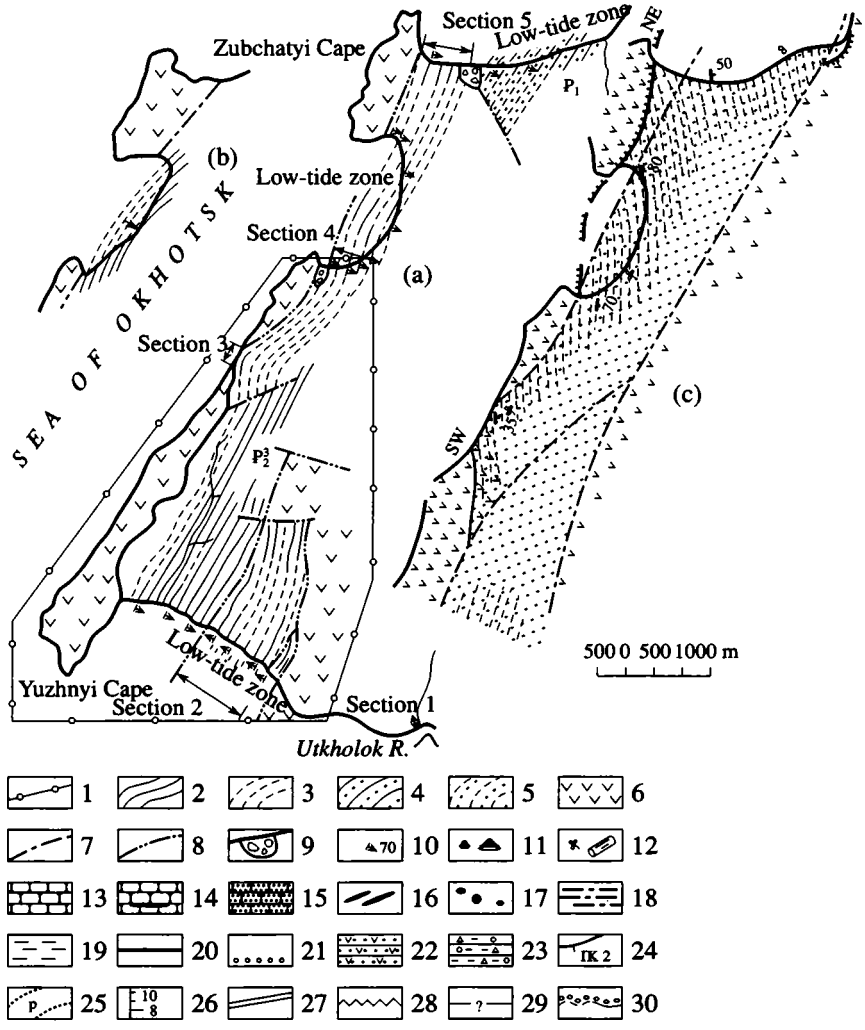

Fig. 2. Geological structure of the southwestern part of the Utkholok Peninsula: (a) after Levin and Fot'yanova (1989, 1990); (b) after Stolbov, VNIGRI, St. Petersburg data of 1983 first in publication; (c) after Chelebaeva and Shantser, 1988.
1, territory mapped by Levin (Kosmoaerogeologiya Geological Production Association, Moscow, 1989); 2, 3, Zubchatyi Mys Formation (P_2^3); bed strike: (2) proven and (3) supposed; 4, 5, lower(?) Paleocene sequence (P_1); bed strike: (4) proven and (5) supposed; 6, volcanics; 7, synclinal axis between the Yuzhnyi Cape and the Utkholok River mouth; 8, tectonic deformations; 9, major rock talus areas in coastal sections; 10, attitude elements; 11, foraminifers, gastropods; 12, plant imprints, trunks; 13, sandstones with varying grain size; 14, fine- to medium-grained sandstones with coal lenses; 15, siliceous sandstones; 16, concretions of calcareous sandstones; 17, rounded concretions of calcareous sandstones; 18, siltstones; 19, mudstones; 20, coal seams; 21, pebbles; 22, quartziferous basic tuffs; 23, silts with detritus and pebbles of volcanics (proluvium?); 24, picket and its number; 25, boundaries of members and their numbers in the section south of the Zubchatyi Cape; 26, samples for foraminiferal analyses and their numbers (short line—foraminifers not found; long line—foraminifers present); 27–30, relationship between sequences: 27, tectonic contact, 28, unconformable bedding, 29, unclear relationships, 30, bedding with washout and basal conglomerate.

Sections of the Utkholok Peninsula (Fig. 1) show the reduced thickness and predominantly sandy–conglomerate facies that are related to the proximity of the Cretaceous basement. Abundant effusive rocks and numerous disjunctive dislocations make the study of the Paleogene stratigraphy in the peninsula difficult. However, almost all sections yield abundant paleontological material, are easily accessible for study, and thus have long attracted the attention of researchers.

Volcanics of all sections in the peninsula are associated with continental sequences, the age of which and, respectively, of volcanics has been debated in recent years. Budantsev (1989) assigns normal sedimentary deposits overlying the volcanics to the Napan Formation of the Tigil' Group, which was dated with some ambiguity but recently has been referred to the late Paleocene–early Eocene. Chelebaeva and Shantser (1988) included these deposits in the newly distinguished Zubchatyi Mys Formation of Danian age and regarded it as a lower unit of the Uleven Group suggested by Klenov (1961). One of the sections in the peninsula (the Ovra Cape locality) was used to substan-

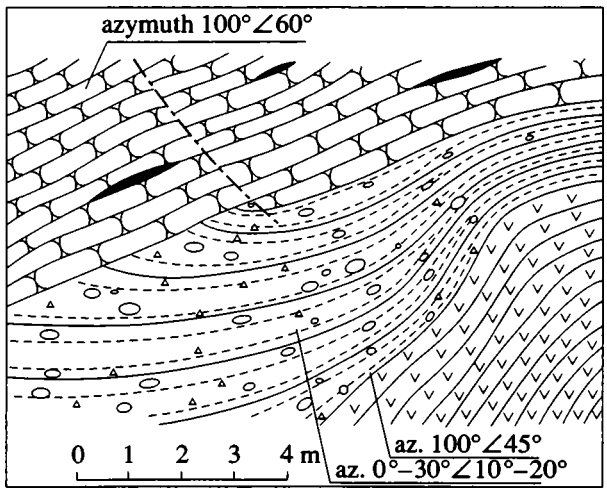

Fig. 3. Relationship between the Zubchatyi Mys Formation and volcanics in Section 3, 5 to 6 km south of the Zubchatyi Cape (compiled by Levin, 1989; see Fig. 2 for symbol explanations).

tiate the concept of the existence of a long stratigraphic hiatus in the Eocene (Gladenkov *et al.*, 1985; *Eotsen* ..., 1991). The researchers consider the hiatus as regional or interregional, ranging from the end of the early to the beginning of the middle Eocene (Chelebaeva and Brattseva, 1985).

The denial of the Tigil' Group validity in Western Kamchatka is related to the existence of an interval hiatus. The group was replaced by the Uleven Group (Gladenkov *et al.*, 1989) with a new range including (from the base upward) the Zubchatyi Mys and Sosopkhan formations (Chelebaev and Shantser, 1988).

Taking into consideration different viewpoints on the structure of separate sections of the peninsula, Fot'yanova and Maslova conducted field works in 1989 and 1990 with the aim to study all (with the exception of Section 3) coastal sections of the peninsula (Figs. 1 and 2). Levin mapped the territory which comprises sections 2 and 3 and the southern part of Section 4 (Fig. 2). Paleobotanic materials and microfaunal samples were taken layer-by-layer from all sections studied. Fot'yanova and Maslova treated the paleobotanic material. Serova studied foraminifers from sections of the Uvuch Mount (using her field collections of 1958) and the Ovra Cape (Fot'yanova and Maslova's collections).

The investigations showed that a group of isolated sections (Fig. 2, sections 2–5), which are located near the Zubchatyi Cape and the mouth of the Utkholok River in the southwestern part of the peninsula, is of particular interest. According to the geological mapping, these sections belong to a single sedimentary sequence, which forms a slight asymmetrical syncline about 4 km wide striking northeastward (Fig. 2). The syncline has a relatively gentle southeastern limb (dip angles average 24°–46° increasing up to 65° near the axis). In Section 4, which is in the northwestern limb of the syncline, dip angles are much greater (50°–70°), increasing up to 75°–80° near the syncline core. The syncline is surrounded by two anticlines in the southeast and northwest, where rocks of the volcanogenic sequence are exposed in their cores (Fig. 2).

The volcanogenic sequence is represented by differentiated calc-alkaline subaerial volcanics: basaltic to dacitic lavas and lava breccias (with prevailing andesites), their coarse-clastic tuffs, and lenses of boulder tuff-conglomerates. Pyroclastics and tuff-conglomerates are confined to the upper part of the section. Effusive rocks are cut in places by subvolcanic basic and intermediate rocks. In some 1–3-m-thick and 50–100-m-long zones, the rocks are hydrothermally altered: silicified, pyritized, and carbonatized. Separate thin quartz and quartz–carbonate veins are observed. The incomplete thickness of the volcanogenic section within the area exceeds 250 m.

The sedimentary sequence is represented by interbedding members of sandstones, siltstones and mudstones with rare gritstone and conglomerate lenses. The sedimentary section as a whole shows a cyclic structure with extremely varying thickness of separate cycles from 0.5 to 100 m. Lower parts of cycles are composed of sandstones, which are replaced up the section by siltstones and then mudstones. In places, a washout is observed at the base of cycles, and sandstones of the next cycle contain unrounded fragments of siltstone and mudstone of the preceding cycle. The thickness of sandstone members varies from 1–2 m to several dozen meters, whereas that of siltstone and mudstone members does not usually exceed 10–15 m. Sandstones composing up to 90% of the sequence prevail at the base of the section (near effusive rocks). Such a pattern was observed near the Yuzhnyi and Zubchatyi capes where lenses of gritstones as well as medium and coarse-pebbled conglomerates several meters long were found in sandstones. At the same time, mudstones and siltstones dominate in the section in the bay situated south of the Zubchatyi Cape. All rocks are rich in plant detritus concentrated in separate layers, although the thickness of these coaly interbeds usually does not exceed 20–30 cm. The thickness of the sediments within the studied territory amounts to, or possibly exceeds 1300 m.

Levin observed the relationship between volcanics and a normal sedimentary sequence in Section 3 (Figs. 1–3). It was established in a coastal area about 15 km long that a laminated bed about 5 m thick occurs over light-gray tuffs and lava breccias of the volcanogenic sequence. The bed is composed of unrounded siltstone and mudstone detritus of widely varying size in places disintegrated to silty grains (from a hundredth fraction of a millimeter to 1 or 2 cm) and slightly cemented. The lamination in the bed is produced by frequent (in 1–5 cm) alternation of coarse-clastic and small-clastic varieties and due to the varying tint of blueish and greenish silt. Separate, well-rounded peb-

bles of silicified tuffs similar to tuffs underlying the bed are observed in layers containing the largest siltstone and mudstone fragments. Some layers in the bed show changeable attitude parameters, which vary from dip azimuth 100° angle 45° at its base, where elements of bedding correspond to those of silicified tuffs, to dip azimuth 0°–30° and angle 10–20° near the top of the bed. At present, the bed is intensively eroded and a talus train is formed. The bed is overlain with the angular unconformity (dip azimuth 70°–100° and angle 60°) by a sequence of well lithified medium- to coarse-grained sandstones with lenses of medium- to coarse-pebbled conglomerates and coaly interlayers.

We consider the bed of loose rocks described above as a past proluvium formed in the period between the formation of tuffs and overlying sandstones. The fact that this period was sufficiently long is also confirmed by a sharp distinction in the extent of hydrothermal alteration of rocks underlying and overlying the proluvium: the intense silicification of tuffs of the volcanogenic sequence that shows abundant quartz veinlets in contrast to almost complete absence of hydrothermal changes in sandstones. The contact discussed in Section 3 is an angular unconformity marking a considerable hiatus (Fig. 3).

Brows of hard sandy rocks are exposed during a low tide in the bay situated south of the Zubchatyi Cape, where Fot'yanova traced the strike of the continental sequence (Figs. 2 and 6). These data on the attitude of rocks in coastal escarpments of the bay permit a statement that exposures of the continental sequence in the southern part of the bay gently bend and extend into the northern part of the bay. Back in 1983, a similar attitude of rocks was mapped by N.M. Stolbov, the geologist from the All-Union Research Geological Prospecting Institute, St. Petersburg. He kindly offered his field sketching of the bay to us and we present it for the first time in this paper (Fig. 2b).

Chelebaeva and Shantser (1988) suggested another interpretation of Sections 3–5 (Figs. 1 and 2). These researchers consider the section situated south of the Zubchatyi Cape (Section 3 according to our numbering) as a basal part of the continental sequence, which is overlain by Sections 4 and 5 (according to our numbering) (Fig. 2b). Thus, they interpret the attitude of the continental sequence as monoclinal with layers dipping northeastward. On this basis, a new Zubchatyi Mys Formation with the stratotype in Section 4 was distinguished. Chelebaeva and Shantser (1988) do not present the description and layer-by-layer paleobotanic characteristics of the stratotype. They published only a generalized list of paleoflora from two sections—the stratotype Section 4 and Section 3 located as far as 2.0–3.0 km from the stratotype. On the basis of the generalized floral complex, the researchers assigned the Zubchatyi Mys Formation to the Danian (Chelebaeva and Shantser, 1988).

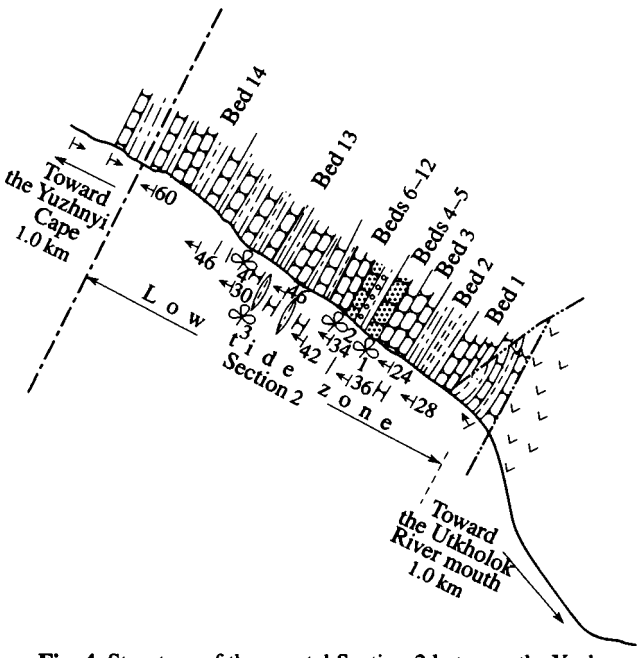

Fig. 4. Structure of the coastal Section 2 between the Yuzhnyi Cape and the Utkholok River mouth (see Fig. 2 for symbol explanations).

Chelebaeva and Shantser (1988) refer almost the whole Section 5 situated north of the Zubchatyi Cape (Figs. 1 and 2a) to the upper part of the Zubchatyi Mys Formation, and the contact with the overlying deposits has not been established in it.

Data obtained suggest that only a part of the deposits exposed in the bay north of the Zubchatyi Cape for less than 1 km along the coastline can be attributed to the continental sequence. The rest of the section belongs to the marine sequence (Fig. 2a). It has a contact with the continental sequence along the northwest trending fault detectable in aerial photographs of this territory. On land, the contact is marked by a coarse talus extended along the coast and coastal escarpments of different height (15–20 m at the continental sequence and up to 60–80 m at the marine sequence). The strikes of both sequences is also different, 10°–20° for the continental sequences and 30°–40° for the marine sequence. The description of Sections 2 and 4 with fossil plants is given below.

SECTION 2. COASTAL SECTION IN THE SOUTHEASTERN LIMB OF THE ANTICLINE BETWEEN THE YUZHNYI CAPE AND THE UTKHOLOK RIVER MOUTH (FIGS. 1, 2, 4, AND 5)

This coastal section of the southeastern limb of the anticline is rich in fossil plants. They are disseminated through the section and abundant only in Units 5, 7, and 13 (Figs. 4 and 5). Fragments of leaves of *Trochodendroides arctica* (Heer) Berry and *Platanus* sp. are found throughout the section. *Metasequoia occidenta-*

lis (Heer) Miki is common among conifers. The first, second, and fourth floral assemblages are identified among plant remains collected in the coastal section, whereas the third one was recovered from a lens of mudstones, which is exposed in the tidal zone only during the lowest tide.

Bed 1. Greenish-gray, uniform, medium- to coarse-grained, thin-platy sandstones. Their platy structure is caused by abundant plant detritus on bedding planes. Sandstones contain layers of gray massive medium-grained sandstones, siltstones, coaly siltstones, and also thin coal seams. The thickness is 38.0 m.

Bed 2. Rhythmic alternation of sandstones similar to previous rocks, dark-gray siltstones, and coaly siltstones with thin (several cm) coal seams. The thickness is 67.0 m.

Bed 3. Sandstones analogous to those from Bed 1 and containing abundant coalified stalks arranged chaotically, not on bedding planes; tree trunks among them are unitary. The thickness is 29.0 m.

Bed 4. Gray sandstones, brick-red on the weathering surface, fine-grained, uniform, siliceous, very hard. The thickness is 13.0 m.

Bed 5. Sandstones similar to those from Bed 1 but still more fine-grained, with layers of siliceous brick-red sandstone. Plant imprins in the upper part of the unit belong to *Platanus asymmetrica* N. Maslova[1], and *Acer arcticum* Heer (Assemblage 1). The thickness is 27.0 m.

Bed 6. Coarse-grained, gray, obscurely bedding siltstones, with rare layers of siliceous brick-red sandstones. In some places, pebble segregations occur on bedding planes. The thickness is 12.0 m.

Bed 7. Medium- to coarse-grained sandstones, light brown on the weathering surface, gray on a fresh shear surface, thin-platy; the platy structure is due to mottled segregations of coalified plant detritus with rare layers of siliceous sandstones, siltstones, coaly siltstones, coals. Coalified wood remains are common. Plant remains are abundant: *Metasequoia occidentalis* (Newb.) Chaney, *Glyptostrobus europaeus* (Brongn.) Heer, *Trochodendroides arctica* (Heer) Berry, *Platanus* cf. *integrifolia* N. Maslova, *Platanus* sp., *Cercidiphyllum eojaponicum* Endo emend. Tanai, *Betula* sp., *Pterocarya?* sp. nov., *Ulmus* sp. nov., *Acer arcticum* Heer, *Rhus* sp. nov., *Nyssidium* sp. (Assemblage 2). The thickness is 21.0 m.

Bed 8. Gray, hard sandstone. The thickness is 9.5 m.

Bed 9. Sandstones similar to those from Bed 7, but with a greater quantity of gray, uniform, hard siltstones. The thickness is 22.5 m.

Bed 10. Greenish-gray, coarse-grained, massive, uniform sandstones in the brow in the tidal zone. The thickness is 6.5 m.

Bed 11. Alternating sandstones similar to those from Bed 7, siltstones and dark gray, almost black mudstones. The thickness is 17.0 m.

Bed 12. Gray, siliceous, hard sandstones with rose clusters of feldspar. The thicknes is 4.5 m.

Bed 13. The member of alternating thin layers of sandstones, siltstones, mudstones, coaly siltstones, and coal seams. Plant imprints are abundant in a lens of dark gray, almost black mudtstones exposed in the tidal zone. The Assemblage 3 identified here comprises *Dryopteris* sp., *Ginkgo* ex gr. *adiantoides* (Ung.) Heer, *Pinus* sp., *Pseudotsuga* sp., *Podocarpus* sp., *Metasequoia occidentalis* (Newb.) Chaney, *Metasequoia* sp. (cone), *Glyptostrobus europaeus* (Brongn.) Heer, *Trochodendroides arctica* (Heer) Berry morpha *"cocculifolia," T. arctica* (Heer) Berry morpha *"cercidifolia," Magnolia* sp. nov., *Tetracentron?* sp. nov., *Hamamelis certa* N. Maslova sp. nov., *Disanthus* sp., *Platanus mabutii* Oishi et Huzioka, *Platanus asymmetrica* N. Maslova, *Platanus zhuravlevii* Medjulianov, *Broussonetia* sp., *Cercidiphyllum eojaponicum* Endo emend. Tanai, *Populus* sp., *Quercus* sp. nov. (dominant), *Castanea* sp., *Fagopsis* aff. *undulata* (Knowlt.) Wolfe et Wehr, *Betula* sp., *Alnus* cf. *protophylloides* Budants. et Golovneva, *Alnus* aff. *miojaponica* Tanai, *Alnus* sp. (cones), *Pterocarya?* sp. nov., *Ulmus* sp. nov., *Tilia?* sp., *Eugenia?* sp., *Vitis* sp., *Acer arcticum* Heer, *Zizyphus* sp., *Celtis* sp., *Rhus* sp., *Vaccinium* sp., *Cordia japonica* Tanai, and *Fraxinus* sp. (3). Ten morphotypes still remain to be determined at the generic level; three of them are represented by entire leafs, one of which is preliminarly determined as genus *Ficus*.

Upsection, the fine-grained platy sandstones yielded *Pinus* sp., *Metasequoia occidentalis* (Newb.) Chaney, *Glyptostrobus europaeus* (Brongn.) Heer, *Trochodendroides arctica* (Heer) Berry morpha *"cocculifolia," Trochodendrocarpus* sp., *Liquidambar?* sp., *Hamamelis certa* N. Maslova sp. nov., *Platanus asymmetrica* N. Maslova, *Platanus* cf. *integrifolia* N. Maslova, *Cercidiphyllum eojaponicum* Endo emend. Tanai, *Populus* sp., *Betula* sp., *Pterocarya kamchatica* (Krysht.) Cheleb., *Rhus* sp., *Broussonetia* sp., *Nyssidium?* sp., and *Trochodendrocarpus* sp. (Assemblage 4). The thickness is 130.0 m.

Bed 14. The member similar to Bed 13, but sandstones dominate in it. The visible thickness is about 90.0 m.

The total thickness is 418.0 m.

The analysis of floral assemblage from Section 2 indicates that two types of landscapes existed during sedimentation—valleys and highlands, possibly with mountains. Floral assemblages 1, 2, and 4 correspond to the intrazonal type of vegetation of low-lying areas with dominating taxa *Platanus, Trochodendroides, Cercidiphyllum, Populus, Pterocarya,* and *Acer arcti-*

[1] When distinguishing the holotype of *Platanus asymmetrica* N. Maslova, the continental sequence in the section between the Yuzhnyi Cape and the mounth of the Utkholok River was attributed to the lower Paleocene (Maslova and Fotyanova, 1990). In the present paper the Zubchatyi Mys Formation is referred to the upper Eocene.

cum. This flora shows a low generic and specific diversity, and differs, though slightly, in the composition of dominating components from the Early Paleogene intrazonal vegetation of Western Kamchatka. Quite a different composition is typical of the floral Assemblage 3, which was collected from thin-bedded mudstones accumulated probably in a lake situated on an elevated land areas. This flora is primarily characterized by a diversity of modern genera of flowering plants. Conifers *Metasequoia, Glyptostrobus* and *Pinus* are also abundant, whereas *Pseudotsuga* and *Podocarpus* are rare. *Quercus* sp. nov. (about 150 imprints) and a small-leaved species of the genus *Betula* (about 40 imprints) dominate among flowering plants. Plants of the families Rosaceae and Fabaceae not yet determined at the generic level, as well as various flowering plants, such as *Tetracentron?, Hamamelis, Disanthus, Broussonitia, Castanea, Fagopsis, Ulmus, Tilia?, Zizyphus, Celtis, Rhus, Cordia japonica* Tanai and other species, impart a peculiar character to this flora. It also includes genera typical of intrazonal Assemblages 1, 2 and 4—*Platanus, Trochodendroides, Cercidiphyllum*, and *Acer arcticum*, each represented by few specimens.

SECTION 4. THE SOUTHERN COAST OF THE BAY SITUATED SOUTH OF THE ZUBCHATYI CAPE (FIGS. 6 AND 7)

Member 1 (pickets 0–10).[2] Tectonic contact exists between normal sedimentary and effusive rocks. Lumpy debris of effusive rocks and sandstones pile up directly on the contact. Gray and greenish-gray, medium-grained sandstones with abundant plant detritus on bedding planes; siltstones and coaly siltstones occur among the debris. Accumulation of well-rounded pebbles of different size were locally observed in sandstones sometimes enclosing isolated pebbles. The upper part of the member contains a frequent alternation of fine-grained uniform sandstones, siltstones, and gray to dark gray mudstones. A layer of almost black coaly siltstones 3.0 m thick is observed at the member top. The thickness of the member is 115.0 m.

Member II (pickets 10–35). Sandstones, siltstones, mudstones, and coaly siltstones with very thin lens-like coal seams. Clearly bedded, fine- to medium-grained, light- to dark-gray sandstones from 4.0 to 5.0 m thick dominate. Siltstones are gray, sometimes highly ferruginate and rust-colored on the weathering surface. Layers of mudstones and coaly siltstones are less thick. Two floral assemblages are defined in this member. Assemblage 1 is confined to the northern part of the bay (Picket 239, Fig. 6) and comprises *Metasequoia occidentalis* (Newb.) Chaney, *Platanus mabutii* Oishi et Huzioka, *Hamamelis certa* N. Maslova sp. nov., *Ulmus* sp. nov., and *Tilia* sp. In addition, a fragment of a large lanceolate leaf with a thick median rib and quite unexpressed (embedded) veining, not yet identified, is found

[2] When describing the section, pickets were set in every 10 m.

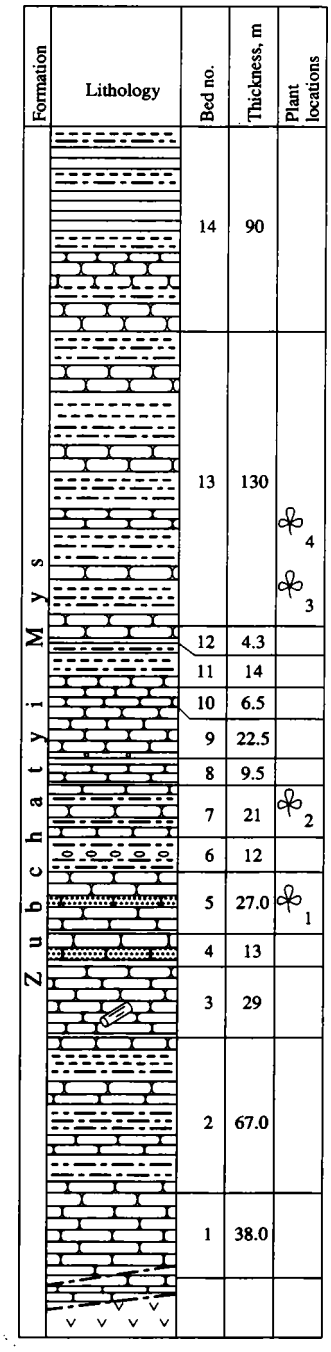

Fig. 5. Section 2 (Zubchatyi Cape–Utkholok River mouth). Compiled by Fot'yanova (see Fig. 2 for symbol explanations).

in this locality. It should be pointed out that a similar plant was recovered for the first time in the upper Eocene Lyukameskaya Formation on the Bogataya River (East Sakhalin Mountains).

The second assemblage was defined in the southern part of the bay near pickets 32 and 34, where rocks yielded *Ginkgo* ex gr. *adiantoides* (Ung.) Heer, *Platanus* cf. *mabutii* Oishi et Huzioka, and *Alnus* aff. *subedoensis* Tanai. The thickness of the member is 120.0 m.

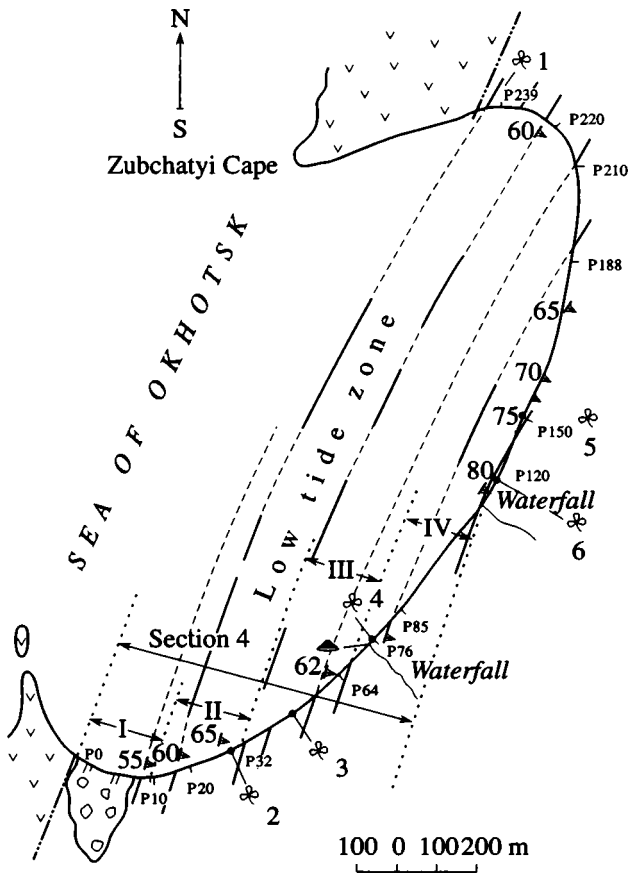

Fig. 6. Strike of Members I–IV of the Zubchatyi Mys Formation stratotype in the section south of the Zubchatyi Cape (compiled by Fot'yanova, 1989; see Fig. 2 for symbol explanations).

Member III (pickets 35–64). The rhythmic member is similar to Member II, but sandstones are more fine-grained, and siltstones dominate. Plant remains found at Picket 50 include *Metasequoia occidentalis* (Newb.) Chaney, *Platanus asymmetrica* N. Maslova, and *Trochodendroides arctica* (Heer) Berry. The thickness is 130.0 m.

Member IV (pickets 64–120). Frequent alternation of fine- and medium-grained sandstones (layers up to 1.0 m thick) with dominating gray, often ferruginized on the surface, clearly-bedded, locally conchoidal siltstones, mudstones, coaly siltstones and coal seams. The member is rich in gastropods (pickets 75, 76) and freshwater mollusks *Unio* (Picket 76). Rare plant imprints belong to (pickets 75, 76; Assemblage 4): *Mallotus orbiculatus* Tanai, *Metasequoia occidentalis* (Newb.) Chaney, *Platanus zhuravlevii* Medjulianov, *Ulmus* sp. nov., and *Trochodendroides arctica* (Heer) Berry or (Picket 150, Assemblage 5) to *Platanus asymmetrica* N. Maslova, and *Trochodendroides arctica* (Heer) Berry and (Picket 120, Assemblage 6) to *Metasequoia occidentalis* (Newb.) Chaney, *Platanus mabutii* Oishi et Huzioka, and *Alnus* cf. *protophylloides* Budants. et Golovneva. The thickness is 128.0 m.

The total thickness of the section 4 is 378.0 m.

The stratotype assemblage of the Zubchatyi Mys Formation (members I–IV) comprises *Ginkgo* ex gr. *adiantoides* (Ung.) Heer, *Metasequoia occidentalis* (Newb.) Chaney, *Trochodendroides arctica* (Heer) Berry, *Hamamelis certa* N. Maslova sp. nov., *Platanus asymmetrica* N. Maslova, *P. mabutii* Oishi et Huzioka, *Alnus* aff. *subedoensis* Tanai, *Alnus* cf. *protophylloides* Budants. et Golovneva, *Ulmus* sp. nov., *Tilia* sp., and *Mallotus orbiculatus* Tanai. Floral assemblages of sections 2 and 4 are not correlatable in number of species (40 and 11, respectively), although they have common species: *Metasequoia occidentalis* (Newb.) Chaney, *Trochodendroides arctica* (Heer) Berry, *Platanus mabutii* Oishi et Huzioka, *P. asymmetrica* N. Maslova, *Hamamelis certa* N. Maslova sp. nov., *Alnus* cf. *protophylloides* Budants. et Golovneva, and *Ulmus* sp. nov. The genus *Hamamelis* is unknow in Paleocene deposits of the North Pacific.

In sections 2 and 4, the generalized plant assemblage of the Zubchatyi Mys Formation shows a high diversity of genera of flowering plants with an evident prevalence of recent genera and predominance of the genus *Quercus*. Single *Trochodendroides* forms and *Acer arcticum* are present. Among conifers, genera *Metasequoia* and *Gluptostrobus* dominate; genera *Pseudolarix, Podocarpus* and others are rare. In the taxonomic composition and structure the assemblage is similar to the Irgirnin assemblage of the Podkagernaya Bay, northwestern Kamchatka, from the stratotype of the formation of the same name (Budantsev and Golovneva, 1986; Fot'yanova and Serova, 1983; Chelebaeva and Brattseva, 1985), to flora of the Ust'-Penzhina Formation of the Penzhina Bay (Ablaev, 1985), to the Seldovia Point type flora from the Cook Bay, Alaska (Wolfe and Tanai, 1980; Fot'yanova, 1984), to the Lyukamenskaya flora of the Bogataya River, Eastern Sakhalin, to the Bolotninskaya flora of southern Primor'e (Ablaev, 1987; Kundyshev and Petrenko, 1987), as well as to the flora of Horizon IV in the Paleogene sections of the Isikari and Cusiro coal basins, Hokkaido (Tanai, 1984, 1990). These floras are dated as late Eocene in age. Fot'yanova refers these floras to the pre-Turgai ecological–chorionomic type (Fot'yanova, 1984).

Section 2 near the Yuzhnyi Bay is suggested to be the parastartotype of the Zubchatyi Mys Formation, because it exhibits the most complete paleobotanic characteristics, which confirms the late Eocene age of the formation.

On the basis of paleobotanic data, Fot'yanova has arrived at the conclusion on a late Eocene age of continental deposits of the Utkholok Peninsula well before the publication of data on the isotopic dating of the volcanic sequence underlying the Zubchatyi Mys Formation (Bagdasaryan *et al.*, 1994), which agree nicely

with paleobotanic data. Isotopic dating (K–Ar) of volcanics from 4 samples yielded ages of 47.5 ± 04, 47.0 ± 0.7, 46.6 ± 2.1, and 45.2 ± 2.0 Ma (middle Eocene). Radiological dating of volcanics (Bagdasaryan *et al.*, 1994) confirms Levin's inferrence on the hiatus between effusive rocks (45–47 Ma) and overlying continental deposits of the Zubchatyi Mys Formation (upper Eocene, about 37–39 Ma), which lasted about 6–8 m.y. It should be noted that two age measurements were obtained for effusive rocks taken near the Yuzhnyi Cape of the Utkholok Peninsula in 1990 in the Absolute Age Laboratory of the Aerologiya Research and Production Association; the values are 55 ± 4 and 64 ± 4 Ma, and they indicate that effusive rocks differing in age may occur in the peninsula.

Relationships between volcanics (middle Eocene) and continental deposits of the Zubchatyi Mys Formation (upper Eocene) in the Utkholok Peninsula are similar to those between effusive rocks of the Kinkil Mys Formation (middle to upper? Eocene) and the overlying continental sequence of the Irgirnin Formation (upper Eocene) in the stratotype section of the Podkagernaya Bay, northwestern Kamchatka (Pogozhev *et al.*, 1963; Budantsev, 1985; Fot'yanova and Serova, 1983; Chelebaeva and Brattseva, 1985).

Thus, our studies do not confirm the Danian age of the Zubchatyi Mys Formation, which Chelebaeva and Brattseva (1985) as well as Chelebaeva and Shantser (1988) assigned it to.

SECTION 6. UTKHOLOK CAPE (FIGS. 1 AND 8)

An isolated section located in the northeast area of the cape is represented by sandstones, siltstones and mudstones with abundant plant detritus and plant imprints at three levels. A thick (about 5 m) sublayer of effusive rocks occurs in the lower part of the section, and directly in the Utkholok Cape the continental sequence is penetrated by a stock-like body of volcanic rocks.

Researchers identified and interpreted the floral assemblage and age of the continental sequence differently. Poyarkova, who was among the first to identify the flora of the Utkholok Cape, dated it Senonian in age (Dyakov, 1957). On the basis of paleobotanic data, Budantsev (1983, 1984, 1989) referred the continental deposits to the upper Paleocene–lower Eocene Napan Formation of the horizon of the same name. Chelebaeva assigned the continental deposits of the Utkholok Cape to the lower part of the Danian–Paleocene Ulevenei Group (Gladenkov *et al.*, 1985).

We distinguished three assemblages in this section (Fig. 8). The first of them includes plant remains collected directly on the Utkholok Cape under the stock-like body of volcanic rocks and confined to the lowermost part of the section. Determined here are *Metasequoia occidentalis* (Newb.) Chaney, *Corylus beringiana* Golovn. morphotype *"vitifolia,"* and *Querexia*

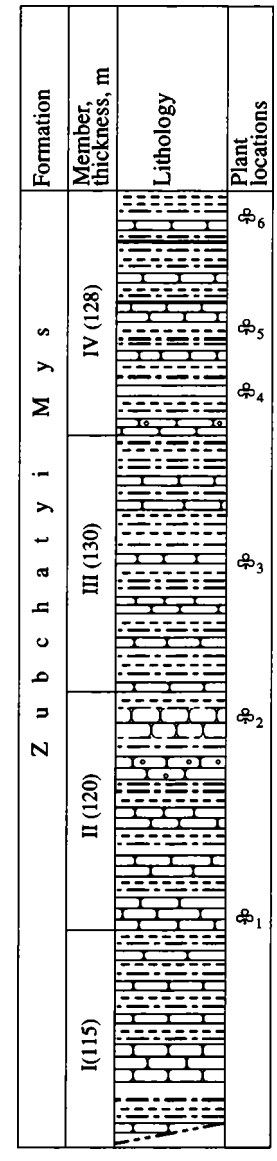

Fig. 7. Section 4, a bay south of the Zubchatyi Cape (see Fig. 2 for symbol explanations).

angulata (Newb.) Krysht. The second assemblage found in the middle part of the sequence comprises *Metasequoia occidentalis* (Newb.) Chaney, *Cephalotaxopsis anadyrensis* Krysht., *Corylus beringiana* (Krysht.) Golovn. morphotype *"betulifolia"* (abundant), *C. beringiana* (Krysht.) Golovn. morphotype *"vitifolia,"* *Corylus* sp. (involucres), and *Peculnea* sp. nov. The only species *Corylus beringiana* (Krysht.) Golovn. morphotype *"betulifolia"* was found in the upper part of the section in a sandstone layer 6–7 m thick.

In our opinion, the floral assemblage from the continental sequence of the Utkholok Cape is similar in general to that of the Rarytkin Formation, the Koryak Upland, of Maastrichtian–Danian age (Golovneva,

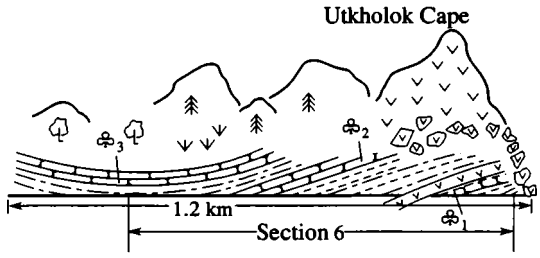

Fig. 8. Structure of the coastal Section 6, the Utkholok Cape (compiled by Fot'yanova, 1990; see Fig. 2 for symbol explanations).

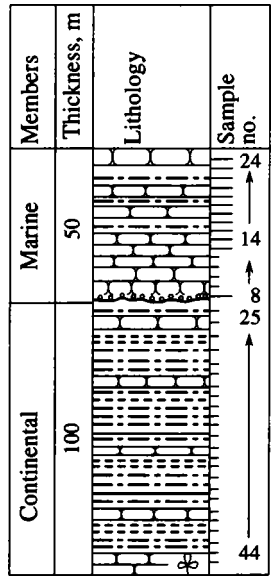

Fig. 9. Section 7, the Ovra Cape (compiled by Fot'yanova, 1989; see Fig. 2 for symbol explanations).

1990). However, the upper age limit of the complex is defined by the presence of the genus *Peculnea* typical of the Gornorechensk assemblage of the lower half of the Maastrichtian and unknown in the Rarytkin assemblage of the upper half of the Maastrichtian–Danian (Golovneva, 1990).

SECTION 7. OVRA CAPE (FIGS. 1 AND 9)

The structure of the section near the Ovra Cape is identically interpreted by all researchers as follows: the lower continental part is transgressively overlain by marine deposits with an angular unconformity and conglomerate at the base (Chelebaeva and Shantser, 1988; *Eotsen* ..., 1991; Serova and Fot'yanova, 1992). However, the identity of the interpretation ends here. Using lithological criteria without citing the paleobotanic data, one group of researchers (Gladenkov, Chelebaeva, Shantser and others, assigned the continental deposits to the Danian–Paleocene Ulevenei Group (*Eotsen* ..., 1991)). The marine deposits overlying them were referred to the Snatol–Kovachin (Gladenkov *et al.*, 1985, *Eotsen* ..., 1991), or merely Kovachin (Chelebaeva and Shantser, 1988) horizon. Thus, these researchers suggest a stratigraphic hiatus between the continental and marine sequences, which falls within the interval of terminal early–initial middle Eocene.

Using paleobotanic data, Fot'yanova substantiated the Maastrichtian (most likely the early Maastrichtian) age of the lower continental member. Serova assigned the overlying marine sequence by the foraminifer assemblage to the lower Paleocene (Serova and Fot'anova, 1992). On the basis of these data, and taking into account the transgressive occurrence of the marine sequence above the continental deposits, one may assume a stratigraphic hiatus, which is confined to the boundary between the Cretaceous and Paleogene, and spans the second half of the Maastrichtian. As the section of the Ovra Cape contains no deposits younger than the early Paleocene, it cannot be used for substantiating the Eocene hiatus suggested by Gladenkov *et al.* (1985).

SECTION 8. UVUCH MOUNT (FIGS. 1 AND 10)

The Tigil' Group has a reduced thickness in the coastal section of the Kovachin Bay northeast of the Uvuch Mount within the southwestern limb of the Kovachin syncline. The Tigil' Group rests on black shales of the Omgon Group (the Turonian–Senonian) with an angular unconformity and basal conglomerate.

Bed 1. Basal conglomerate. In the lower part, the rock consists of well-rounded pebbles of Cretaceous rocks, in the upper part they are mixed with acute-angled fragments of Cretaceous sandstones. Interlayers of sand and clay occur between both parts. The visible thickness is 4.0 m.

Bed 2. Greenish-gray obliquely laminated sandstones with interbeds and strips of rusty sandstones and poorly expressed stratal nodules. Sandstones are layered in the upper part; the layering is due to alternation of loose weakly cemented sandstones and hard calcareous nodular sandstones; the thickness of individual layers is up to 1.5 m. Interlayers of fine-grained ashy-gray sandstones with coaly intercalations of polymictic medium- and small-pebbled conglomerates 0.1–0.2 m thick are rare.

Foraminifers are represented by individual agglutinated forms *Silicosigmoilina californica* Cushm. et Church (Sample 818), *Bathysiphon nodosariaformis* Subb., *Haplophragmoides glabratus* Cushm. et Waters, and *Ammodiscus penny* Cushm. et Jarv. (Sample 822). The thickness is 45.0 m.

Bed 3. Loose, fine-grained, greenish-gray, obliquely laminated sandstones with calcareous nodules and small lenses of coal. The thickness is 35.0 m.

Bed 4. Greenish-brown sandstones ferruginized in the lower part, and greenish-gray in the upper part; they are loose, fine-grained, with abundant plant detritus and numerous rounded nodules of calcareous sandstones. Calcareous foraminifers from the rocks include *Quinqueloculina subarenaria* Cushm., *Globulina inaequalis* Reuss, *Cribrononion* aff. *saitoi* (Asano et Murata), *Cibicides natlandi aequaensis* Beck, *Cibicides bayleyi* Beck, and *Cibicides* sp. nov. The thickness is 45.0 m.

Bed 5. Clayey, dirty-green and brown, fine-grained, loose sandstones with abundant coalified plant detritus and two interlayers of coarse-pebbled unsorted conglomerates at the base. The thickness is 32.0 m.

Bed 6. Clayey, gray-green, loose sandstones rich in volcanogenic material, with interlayers of more dense dove-gray sandstones. The thickness is 25.0 m.

According to Krishtofovich (1947), deposits from Units 5 and 6 represent a stratigraphic analogue to the Kovachin Group of the Tochilino reference section.

Agglutinated foraminifers found in Unit 2, are similar in species composition to those identified by Fregatova in basal conglomerates of the Mainach section (*Eotsen* ..., 1991). Analogues of this assemblage are widespread on the continental margin of the North Pacific: in the Danian–lower Paleocene deposits of Kamchatka and the Koryak Upland (the Inetyvayam and Ivtygin formations); in Sinegor'e beds of Sakhalin (Serova, 1987); in the *Silicosigmoilina californica* Zone of the Lodo Formation, California (Mallory, 1970), and in the Siome Formation of the Nemuro Group, Hokkaido (Yoshida, 1969). The presence of this assemblage in Units 1 and 2 of the Uvuch section confirms the viewpoint of D'yakov (1957), Krishtofovich (1947), Pleshakov (1939) and others that Danian–lower Paleocene sandstone facies in the Uvuch Mount section are analogous to Khulgun conglomerates.

Another representative foraminifer assemblage with dominating species *Cibicides baileyi* Beck was found in the lower part of Unit 4. Numerous mollusk shells were observed in the same interval (Krishtofovich, 1947; *Eotsen* ..., 1991). This assemblage was distinguished by Krishtofovich as characteristic of the stratotype of the upper *Nucula yohanseni* Subzone of the Uvuch Horizon, Snatol Formation. Sandstones from Unit 3 with basal conglomerates, in which foraminifers were not found, may correspond to the lower subhorizon of the Uvuch Horizon or to some part of it. In this case, the hiatus in the Uvuch section may correspond to the interval from the late Paleocene to the mid-middle Eocene.

Thus, two hiatuses, not one, are distinguished in the Uvuch Mount section (*Eotsen* ..., 1991)—at the boundary between the Cretaceous and Paleogene, and in the late Paleocene–middle Eocene interval. Lower Paleocene deposits are observed in the section, whereas deposits of the Snatol Horizon are apparently lacking here.

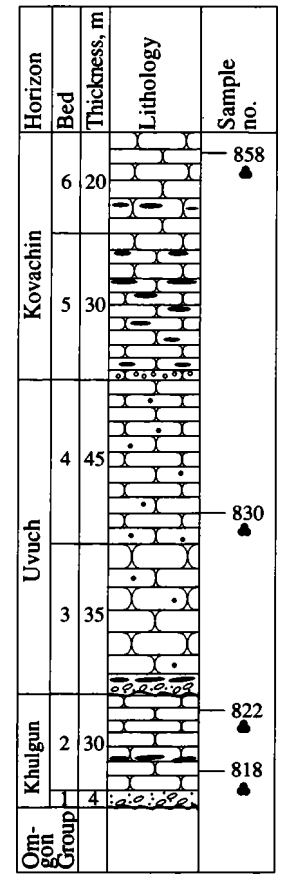

Fig. 10. Section 8, the Kvachin Bay–Uvuch Mount (compiled by Serova; see Fig. 2 for symbol explanations).

CONCLUSION

The studies conducted have revealed the following:

(1) Chelebaeva and Shantser (1988) as well as Brattseva (Chelebaeva and Brattseva, 1985) suggested the name *Zubchatyi Mys Formation* to deposits of different age, from the early Maastrichtian to the late Eocene (Fig. 11). This formation is of the late Eocene age in the stratotype section of the Zubchatyi Mys, in coastal escarpments of the bay south of the Zubchatyi Cape (Section 4), in the bay north of the Zubchatyi Cape (Section 5), and 5.0–6.0 km south of the Zubchatyi Cape (Section 3). The strike of the formation coincides with that of the shoreline; it forms the northwestern limb of the syncline. The formation does not represent a sequence of submeridional north-northwestern trend, the section of which is increasing along the shoreline from southwest to northeast, as Chelebaeva and Shantser interpret it (1988).

(2) In Section 6 (the Utkholok Cape) and Section 7 (the Ovra Cape) (Fig. 1), the Zubchatyi Mys Formation distinguished as an equivalent to the lower part of the Ulevenei Group (Chelebaeva and Brattseva, 1985; Chelebaeva and Shantser, 1988) is of Maastrichtian (most likely early Maastrichtian) age, and the basal part

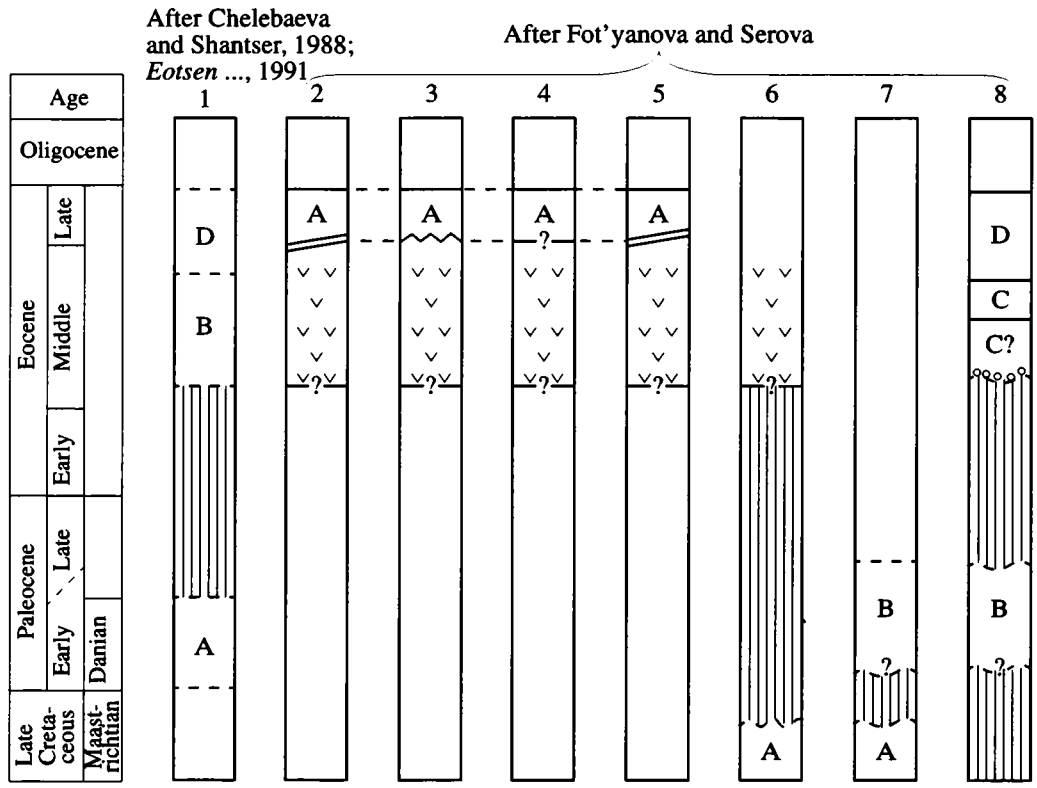

Fig. 11. Position of the Zubchatyi Mys Formation (A), Snatol (B), Uvuch (C), and Kovachin (D) deposits of the Utkholok Peninsula in the Paleogene scale (compiled by Fot'yanova and Serova): 1, after Chelebaeva and Shantser, 1988 and *Eotsen* ..., 1991; 2–8, after Fot'yanova and Serova (see Fig. 1 for names of sections 2–8).

of the Snatol deposits is characterized by the Danian–lower Paleocene foraminifer assemblage as in Section 8 of the Uvuch Mount (Serova and Fot'yanova, 1992).

(3) The late Eocene age of the Zubchatyi Mys Formation agrees well with the radiological dating of underlying volcanics (middle Eocene; Bagdasaryan *et al.*, 1994) and eliminates a drastic conflict between the middle Eocene age of volcanics and Danian (according to Chelebaeva) age of overlying continental deposits (Bagdasaryan *et al.*, 1994).

(4) A sequence exposed in the bay north of the Zubchatyi Cape and separated from the coal-bearing deposits of the section by an unconformity (Fig. 2) is irrelevant to the Zubchatyi Mys Formation. By lithology, the sequence is similar to the Danian–lower Paleocene deposits of the Ovra Cape section.

(5) In relation to the above discussion, we cannot agree with certain propositions of the standard and correlation schemes of the Paleogene suggested by a group of researchers (Gladenkov *et al.*, 1989). We consider it impermissible to use the paleontologic assemblage of the Zubchatyi Mys Formation of Western Kamchatka as a characteristic F1 assemblage for the lower Paleocene Ivtygin and Tarkhov–Vereshchagin horizons as it is of late Eocene age.

(6) The Ulevenei Group also cannot be used as a valid unit, because its lower part (the Zubchatyi Mys Formation) is younger (late Eocene) than the upper part (the Sosopkhan Formation, early Paleocene).

The description of a new genus *Hamamelis*, which is similar in morphology to recent species *H. mollis* Oliv. and *H. virginiana* L. below is given. Until the present time, the genus representatives were not found in deposits of Kamchatka older than the late Eocene, like some other genera of the family Hamamelidaceae, for instance *Parrotia*, and *Disanthus* (Maslova, in press). The subtropical genus *Mallotus* (*M. orbiculatus* Tanai), of the family Euphorbiaceae was identified for the first time in Kamchatka in the stratotype of the Zubchatyi Mys Formation. It was previously known only in

Plate I. Fossil plants of the late Eocene (the Utkholok Peninsula). (1, 2, 5) *Hamamelis certa* N. Maslova sp. nov.; (1) Holotype. Sample 4395/318a, PIN RAS, leaf imprint, Western Kamchatka, Utkholok Peninsula, a bay south of Zubchatyi Cape; (2) ditto, ×0.6; (5) Sample 4395/190, PIN RAS, leaf imprint, Western Kamchatka, Utkholok Peninsula, between the Yuzhnyi Cape and Utkholok River mouth; (3, 4) *Mallotus orbiculatus* Tanai; (3) Sample 4395/341, PIN RAS, leaf imprint, Western Kamchatka, Utkholok Peninsula, a bay south of the Zubchatyi Cape; (4) ditto, ×0.6; (1–5) the Zubchatyi Mys Formation, upper Eocene.

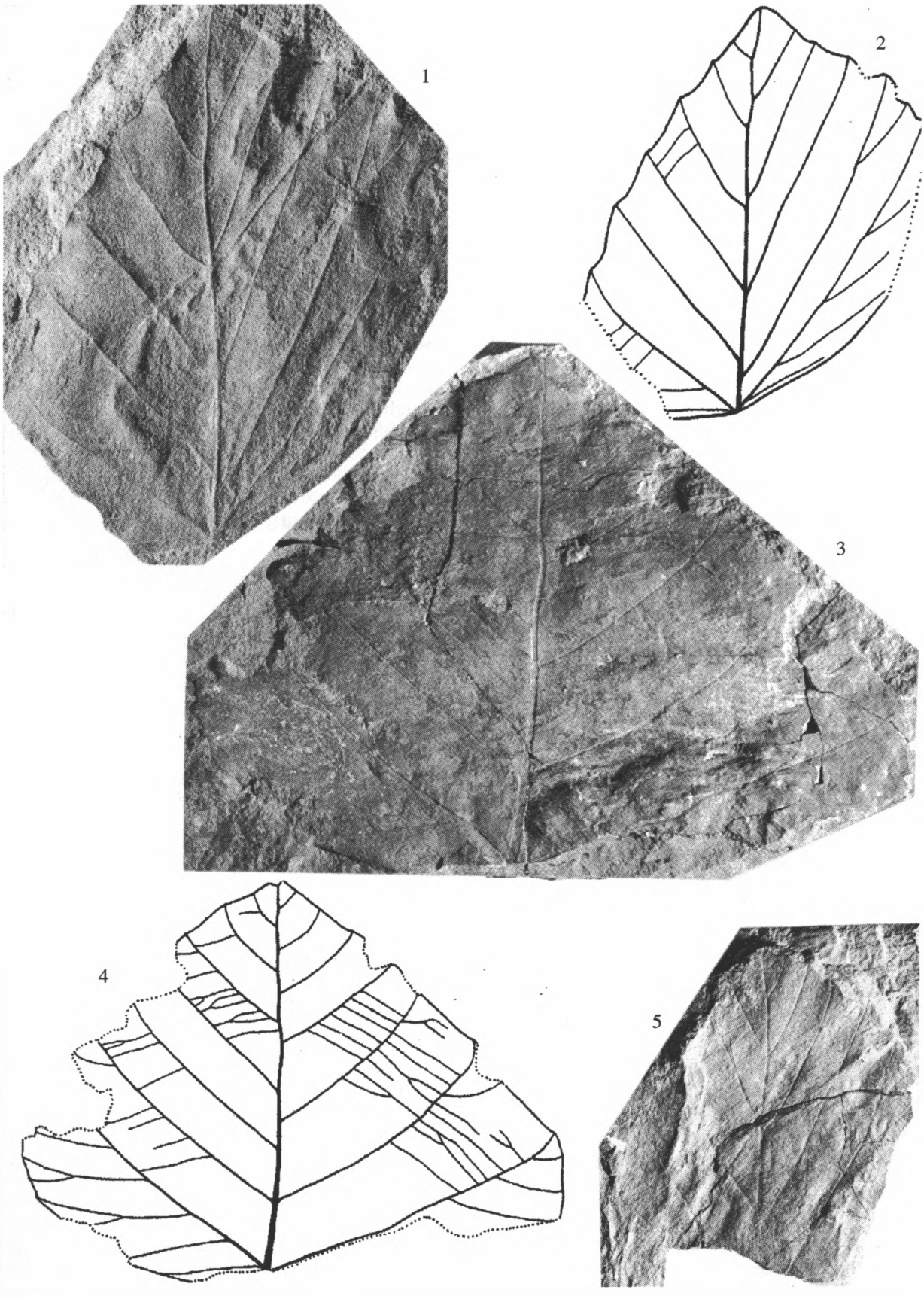

Plate I.

the Isikari coal basin of Hokkaido, in floral Horizons III and IV spanning the interval from the second half of the middle to the beginning of the upper Eocene (Tanai, 1990).

Hamamelis certa N. Maslova sp. nov.[3]
Plate I, figs. 1, 2, and 5

Holotype. Sample 318a, Collection no. 4395, Paleontological Institute, Russian Academy of Sciences, Moscow, almost a complete leaf imprint; Western Kamchatka, the Utkholok Peninsula, the bay south of the Zubchatyi Cape; the Zubchatyi Mys Formation, upper Eocene, Plate I, figs. 1 and 2.

Material. Four imprints of leaves of various preservation and about 10 small fragments of leaves.

Description. An asymmetrical, rhomboid–elliptical or rhomboid–oval leaf with a scalene base and a blunted top. A stalk has not been preserved. The principal rib is wavy near the leaf top. Basal ribs are well expressed and different in length; one of them is trending to more than a half length of the leaf. Basal ribs are similar in thickness to secondary ribs and give 4 to 5 (more rarely up to 7) basiscopic and craspedodromous branching. Deviation angles of basal ribs range from 35° to 60°. Secondary ribs in amounts of 4 to 5 pairs are as a rule curved; rarely the lower ones are straight at the base, diverging at an angle of 25°–40°. The first two pairs of secondary ribs gave 2 basiscopic bifurcations. Tertiary ribs make an angle with the principal rib in the lower part of the leaf, being perpendicular to it in the upper part. The leaf edge is wavy–serrate; the serration begins above one third of the leaf length. Crenations are large, not high, and rounded; some of them end with a short cusp representing the rib ending.

Comparison. The species differs from *H. protojaponica* Tanai et N. Suzuki, described from the upper Miocene of Japan (Tanai and Suzuki, 1965) and the middle Miocene of Korea (Huzioka, 1972), in its pronounced basal ribs, which give basiscopic bifurcations ending in the leaf edge.

The species is most similar to *H. miomollis* Hu et Chaney first described from Miocene deposits of the Shandun Province, northeastern China (Hu and Chaney, 1938). It differs in a curved principal rib, smaller angle of deviation of secondary ribs, a smaller number of basiscopic bifurcations of basal ribs, and larger crenations.

The species differs from *H. ochotensis* Chelebaeva in a pronounced leaf asymmetry, curved secondary ribs, and absence of bifurcations from the lower basiscopic rib.

Remarks. H. certa demonstrates basic generic signs of recent *Hamamelis*—the asymmetric rhomboid form of a leaf, asymmetric leaf base, wavy principal rib, curved secondary ribs, and wavy-serrate edge of a leaf. The only distinctive feature is the more developed area of a leaf separated by basal ribs, as compared to most leaves of recent *Hamamelis*. This feature is typical of other fossil *Hamamelis*. *H. certa* exhibits the most similarity with recent *H. mollis* Oliv. and *H. virginiana* L.

Locality. Western Kamchatka, the Utkholok Peninsula, the Zubchatyi Mys Formation, upper Eocene.

Mallotus orbiculatus Tanai
Plate I, figs. 3 and 4

Holotype. Sample PP 10349. Stored in the National Science Museum, Tokyo, Japan. Hokkaido, the Ubari coal basin, Reisunzan. The Ikusunbezu Formation, floral Horizon IV, the upper Eocene. Plate I, fig. 2; fig. 3, J, K.

Material. One leaf imprint.

Description. A whole, rounded–triangular, very broad leaf 9 cm high, 13 cm wide. The base is truncated, the top is shortly acuminate. The principal rib is very thick in the lower half of the leaf, abruptly becoming thinner in the upper part. Basal ribs in one pair are straight, craspedodromous. Four to six curved basiscopic bifurcations sometimes show branching and end in craspedodromous mode. Tertiary ribs are weak, diverse, almost straight, sometimes Y-shaped or gently curved, and closely-spaced. The leaf edge is almost entire, with slightly outlined low crenulation, which end with glandules.

Comparison. Morphologically isolated species with craspedodromous secondary and basiscopic ribs.

Remarks. Tanai (1990) considers the genus *Mallotus* as an element of the tropical flora occurring in the transitional middle- to late Eocene flora of Hokkaido along with other genera of the family Euphorbiaceae (*Acalyphe, Alchornea, Hura*).

Range and distribution. The terminal middle Eocene: Hokkaido, the Uruiyu Formation. The basal upper Eocene: Hokkaido, the Ikusunbezu Formation. The upper Eocene: Western Kamchatka, the Utkholok Peninsula, the Zubchatyi Mys Formation.

Reviewers L.Yu. Budantsev, M.A. Akhmet'ev, and A.S. Alekseeva.

[3] The species name is from the Latin *certus*, which means evident, apparent.

REFERENCES

Ablaev, A.G., *Flory Koryaksko-Kamchatskoi oblasti i voprosy stratigrafii kontinental'nogo kainozoya* (Floras of the Koryak-Kamchatka Region and the Stratigraphy of the Continental Cenozoic), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1985.

Ablaev, A.G., *Geologiya i istoriya flor poberezhii Yaponskogo morya (v pozdnemelovoe i tretichnoe vremya)* (Geology and the History of Floras of the Japan Sea Coast in the Late Cretaceous and Tertiary), Moscow: Nauka, 1987.

Bagdasaryan, G.P., Gladenkov, Yu.B., and Shantser, A.E., Isotopic Dating of Paleogene and Neogene Volcanogenic Sequences of Kamchatka, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 3, pp. 87–91.

Budantsev, L.Yu., Fossil Flora and and Phytostratigraphy of the Paleogene in the Western Kamchatka, in *Problemy paleofloristiki i stratigrafiya* (Problems of Paleobotany and the Stratigraphy), Leningrad: Nauka, 1989, pp. 17–31.

Budantsev, L.Yu., Fossil Flora and and Phytostratigraphy of the Paleogene in the Western Kamchatka, in *Problemy paleofloristiki i stratigrafiya* (Problems of Paleobotany and the Stratigraphy), Leningrad: Nauka, 1989, pp. 17–31.

Budantsev, L.Yu., *Istoriya arkticheskoi flory epokhi rannego kainofita* (The Arctic Flora History of the Early Cenophytic), Leningrad: Nauka, 1983.

Budantsev, L.Yu., Phytostratigraphy of the Continental Paleogene of Western Kamchatka, in *Materialy po stratigrafii i paleogeografii Vostochnoi Azii* (Materials on Stratigraphy and Paleogeography of Eastern Asia), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1984, pp. 53–58.

Budantsev, L.Yu., Stratigraphic Position and Age of the Kinkil'skii Mys Formation in Northwestern Kamchatka, in *Stratigrafiya kainozoya Dal'nego Vostoka SSSR* (The Cenozoic Stratigraphy of the USSR Far East), Leningrad: Vses. Nauch.-Issled. Geol.-Razved. Inst, 1985, pp. 62–77.

Budantsev, L.Yu. and Golovneva, L.B., A New Species of the *Alnus* Genus (Betulaceae) with Peltate Leaves in the Late Eocene Flora of Northwestern Kamchatka, *Botan. Zh.*, 1986, vol. 71, no. 2, pp. 246–253.

Chelebaeva, A.I. and Brattseva, G.M., On the Paleogene Climatostratigraphy by Paleofloras (the Northern Pacific and Adjacent Regions), in *Korrelyatsiya kainozoiskikh tolshch Dal'nego Vostoka* (Correlation of Cenozoic Sequences of the Far East), Moscow: Geol. Inst. Akad. Nauk SSSR, 1985, part 2, pp. 157–209.

Chelebaeva, A.I. and Shantser, A.E., New Data on the Early Paleogene of Western Kamchatka, in *Litologiya i stratigrafiya mezozoya i kainozoya vostochnykh regionov SSSR* (Lithology and Stratigraphy of the Mesozoic and Cenozoic of the Eastern USSR), Moscow: Nauka, 1988, pp. 135–148.

D'yakov, B.F., The Facies Analysis of Tertiary Deposits and Basic Features of the Paleogeography in the Tigil District of Western Kamchatka, *Tr. Vses. Nauch.-Issled. Geologorazved. Inst.*, 1957, no. 102, pp. 37–54.

Eotsen Zapadnoi Kamchatki (The Eocene of Western Kamchatka), Moscow: Nauka, 1991.

Fot'yanova, L.I., The Late Eocene Turgai Flora of Ancient Beringia, *Botan. Zh.*, 1984, vol. 69, no. 4, pp. 425–436.

Fot'yanova, L.I. and Serova, M.Ya., Paleogene Biostratigraphy of Northwestern Kamchatka (Podkagernaya Bay), *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1983, no. 10, pp. 65–72.

Gladenkov, Yu.B., Brattseva, G.M., Sinel'nikova, V.N., *et al.*, *Stratigraficheskaya skhema paleogena Dal'nego Vostoka* (Stratigraphic Scheme of the Far East Paleogene), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1989, pp. 161–168.

Gladenkov, Yu.B., Sinel'nikov, V.N., Chelebaeva, A.I., and Shantser, A.E., Problems of the Paleogene in the Tigil District of Western Kamchatka, in *Korrelyatsiya kainozoiskikh tolshch Dal'nego Vostoka* (Correlation of Cenozoic Sequences of the Far East), Moscow: Geol. Inst. Akad. Nauk SSSR, 1985, part 1, pp. 45–55.

Golovneva, L.B., The Maastrichtian–Danian Flora of the Rarytkin Range (the Koryak Upland), *Cand. Sci. (Biol.) Dissertation*, Leningrad: Botanical. Inst. Russ. Akad. Sci., 1990.

Hu, H.H. and Chaney, R.W., A Miocene Flora from Shantung Province, China, *Carnegie Inst. Wash. Publ.*, 1940, parts 1, 2, nos. 507, 508, pp. 1–47.

Huzioka, K., The Tertiary Floras of Korea, *J. Mining Coll. Akita Univ., Ser. A.*, 1972, no. 1, pp. 1–83.

Klenov, E.P., Stratigraphy of Tertiary Deposits of Western Kamchatka, in *Unifitsirovannye stratigraficheskie skhemy Severo-Vostoka SSSR* (Standard Stratigraphic Schemes of the Northeastern USSR), Leningrad: Gosnauchtekhizdat, 1961, pp. 151–154.

Krishtofovich, L.V., Stratigraphy and Fauna of the Tigil' Sequence of the Kamchatka Western Coast, *Tr. Vses. Nauch.-Issled. Geologorazved. Inst., Nov. Ser.*, 1947, no. 23, p. 151.

Kundyshev, A.S. and Petrenko, T.I., On the Age of the Bolotnaya Fossil Flora of Southern Primor'e, in *Palinologiya Vostoka SSSR* (Palynology of the Eastern USSR), Vladivostok: Dal'nevost. Nauch. Tsentr Akad. Nauk SSSR, 1987, pp. 53–59.

Mallory, S., Lower Tertiary Foraminifera from the Media Aqua Creek Ranges Area, Kern County, California, *Res. Rep. H. Thomas Burke Mem. Washington State Mus., Iniv.*, Washington, 1970, no. 2.

Maslova, N.P., New Species of *Corylopsis, Disanthus* and *Parrotia* from Late Eocene Deposits of Kamchatka, Russia, *Botanical J. Linn. Soc.* (in press).

Maslova, N.P. and Fot'yanova, L.I., Revision of *Platanus mabutii* (Platanaceae), and New Species of Paleogene Sycamores in the Far East, *Botan. Zh.*, 1990, vol. 75, no. 5, pp. 699–706.

Pleshakov, I.B., Tertiary Deposits of the Utkholok Region of Western Kamchatka, *Trudy Vsesoyuzn. Nauch.-Issled. Geol.-Razved. Inst., Ser. A*, 1939, no. 123.

Pogozhev, A.G., Golyakov, V.I., and Arsanov, A.S., Stratigraphy of Paleogene and Neogene Deposits of the Eastern Coast of the Penzhina Bay, in *Geologiya Koryakskogo nagor'ya* (Geology of the Koryak Upland), Moscow: Gosnauchtekhizdat, 1963, pp. 122–132.

Resheniya 2 Mezhvedomstvennogo stratigraficheskogo soveshchaniya po melu, paleogenu i neogenu Koryakskogo nagor'ya, Kamchatki, Komandorskikh ostrovov i Sakhalina (Resolutions of 2nd Interdepartmental Stratigraphic Conf. on the Cretaceous, Paleogene and Neogene of the Koryak Upland, Kamchatka, Komandor Islands and Sakhalin), Magadan: Sevvostokgeologiya, 1982.

Serova, M.Ya., *Foraminifery i biostratigrafiya Severnoi Patsifiki na rubezhe mela i paleogena* (Foraminifers and Biostratigraphy of the North Pacific at the Cretaceous–Paleogene Boundary), Moscow: Nauka, 1987.

Serova, M.Ya. and For'yanova, L.I., On the Stratigraphic Hiatuses in the Paleogene of Western Kamchatka, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1992, vol. 67, no. 5, pp. 71–77.

Shantser, A.E., Chelebaeva, A.I., and Kraevaya, T.S., Correlation of Cenozoic Sequences of the Far East, *Preprint of Geol. Inst., USSR Acad. Sci.*, Moscow, 1985, part 1, pp. 45–55.

Tanai, T., *Floristic Changes of Japan during the Late Cretaceous and Early Tertiary*, Hokkaido Univ., 1984, pp. 1–36.

Tanai, T., Euphorbiaceae and Icacinaceae from the Paleogene of Hokkaido, Japan, *Bull. Nat. Sci. Mus., Ser. C: Geol (Tokyo)*, 1990, vol. 16, no. 3, pp. 91–118.

Tanai, T. and Suzuki, N., Late Tertiary Floras from Northeastern Hokkaido, Japan, *Spec. Pap. Palaeontol. Soc. Jap.*, 1965, no. 10, pp. 1–118.

Wolfe, J.A. and Tanai, T., The Miocene Seldovia Point Flora from the Kenai Group, Alaska, *U.S. Geol. Surv. Prof. Pap.*, 1980, no. 1105, pp. 1–52.

Yoshida, S., Biostratigraphic Significance of the Late Cretaceous to Early Tertiary Planktonic Foraminifera in Japan, in *Proc. Sci. Int. Conf. Plankton. Microfossils. 1967*, Geneva, 1969, vol. 2, pp. 138–145.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 567–579. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 47–60.
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Regional Angular Unconformities in the Cenozoic Sequences of Kamchatka

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Abstract—Several angular unconformities have been recognized in Cenozoic sections of the Kamchatka region located in the Pacific–Asia transition zone. They are of a regional scale and confined to certain levels: the Cretaceous–Paleogene boundary (most likely, of limited extent), and pre-middle Eocene, pre-Pliocene, and, probably, Quaternary levels. These unconformities reflect short-time tectonic events that were accompanied by the formation of three major fold-thrust (or accretionary) zones in Kamchatka.

Key words: *Cenozoic, angular unconformities, hiatuses, structural-formational zones, accretion zones, tectonic deformations.*

INTRODUCTION

Angular unconformities observed in sequences always suggest important tectonic events that have occurred in the time interval between the formation of rock assemblages below and above the particular unconformity. However, there is commonly a considerable time gap between the youngest deformed and oldest overlying strata, which makes the precise dating of these events difficult. In those areas, where geological structure with angular unconformity surfaces traceable over large territories is relatively simple and well-studied, the problem of event dating can be solved by the simple analysis of geologic maps and sequences. However, in most fold regions, whose complicated structure is insufficiently studied and unconformity surfaces can be observed only in isolated outcrops and in limited areas separated by dozens or hundreds kilometers, the correlation of tectonic events resulting in angular unconformities call for certain assumptions. First, one should assume a synchronism and regional extent of intense tectonic deformations within major domains with uniform section structure. In the Russian literature, these domains are called structural-formational zones. Second, the similarly regional character of post-deformation uplift and erosion should also be assumed. The stratigraphic boundary between two rock units that resulted from these events within the single structural-formational zone should not be conformable in one area and unconformable in another. Naturally, this leads to a limited scope of tectonic events to be correlated. Among these events, of primary importance are the so-called orogenic phases—relatively short-term episodes of a general contraction resulting in both intense deformation of sedimentary sequences and crust thickening that causes isostatic uplift of the deformed sequences.

Keeping these assumptions in mind, the age of deformations that resulted in angular unconformities observed in outcrops is determined by excluding those time intervals, to which conformably bedded sequences correspond in the particular structural–formational zone. This approach is supplemented by direct unconformity dating in those rare outcrops where lower and upper rock complexes are sufficiently close in age.

Below, we analyze, using this approach, angular unconformities in Paleogene and Neogene sections of Kamchatka.

REGIONAL REVIEW OF ANGULAR UNCONFORMITIES IN CENOZOIC SEQUENCES OF KAMCHATKA

Angular unconformities in this region have been mentioned in many publications. However, no comprehensive analysis of these observations has been performed thus far. In addition, geologic materials on some key areas, where unconformities are distinctly reflected in the sections, were until recently insufficient. Moreover, stratigraphy of many areas of the Kamchatka Peninsula was not sufficiently advanced to permit the reliable correlation of sections and unconformities. New data on these issues, which were collected during recent years, and advanced stratigraphic schemes with defined zonal units allow geologic events to be correlated on a considerably more reliable basis than before (Gladenkov *et al.*, 1991, 1992).

The factual material considered below is grouped according to the tectonic zonation of the region (*Geologiya* ..., 1964). In the Kamchatka region, several

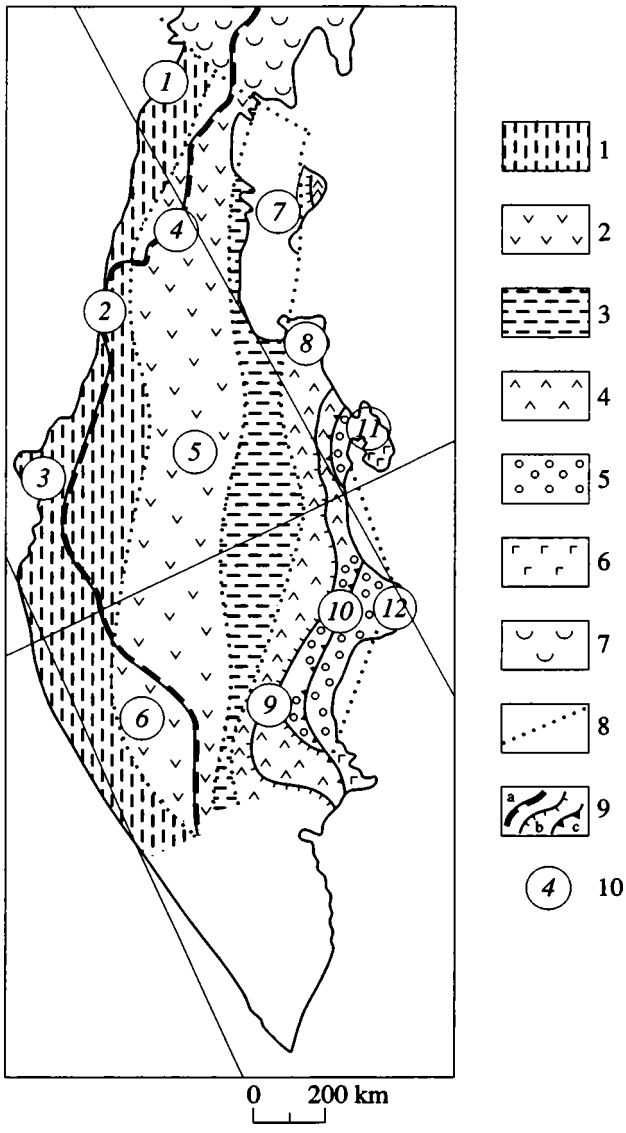

Fig. 1. Main Cenozoic formational zones of Kamchatka. 1, Western Kamchatka; 2, the Sredinnyi Range zone; 3, the Central Kamchatka depression; 4, the zone of eastern ranges; 5, the Tyushevka trough; 6, the zone of eastern peninsulas; 7, the Olyutor structural-formational zone; 8, boundaries of structural-formational zones; 9, major overthrusts (a, Lesnaya, b, Vetlovaya, c, Grechishkin); 10, location of areas coresponding to columns in Fig. 7.

Cenozoic structural-formational zones are traditionally defined. These zones correspond approximately to the main morphological domains of the peninsula (Fig. 1). From west to east, these are: (1) *the Western Kamchatka zone* comprising lowlands along the Sea of Okhotsk coast and piedmonts of the western Sredinnyi Range; (2) *the Sredinnyi Range zone*; (3) *the Central Kamchatka trough* comprising the Central Kamchatka depression in the south and the Litke Strait coast in the north; (4) *the zone of eastern ranges* also including the Ozernoi Peninsula and southeastern Karaginskii Island: and (5) *the zone of eastern peninsulas* (Shipunskii, Kronotskii, and Kamchatskii Mys). The narrow and only partly exposed *Tyushevka trough*, which can be considered to represent the independent srtuctural-formational zone, is defined between two latter zones. The boundaries between the above-listed zones are in general arbitrary and of different origin. The southernmost part of the Kamchatka Peninsula with its mostly volcanogenic sequences is excluded from the present analysis because the stratigraphy of these sequences is now under serious revision. In addition, unconformities within the Pliocene–Quaternary sections are also excluded from consideration in the present study.

Western Kamchatka. In this area, Cenozoic deposits are widely spread and are represented by marine shelf and continental sediments and volcanics. The entire southern part of the zone (south of the Rassoshina River) is overlain by loose Quaternary deposits. In the north, the best-known Cenozoic sections were studied in the Sea of Okhotsk cliffs, where stratotypes of most regional stratigraphic Paleocene to Pliocene units are located.

The lowermost Cenozoic strata referred to the Paleocene were described, in particular, north of the Palana. In this area, the Anadyrka Formation composed of continental sandy-conglomerate sediments is assigned to this time interval. In the Anadyrka River mouth area, this latter is unconformably overlain by the middle Eocene continental deposits (the Ust'-Anadyrka Formation) (Gladenkov *et al.*, 1991). Figure 2 shows the contact between these two units.

In the Kakhtanskii Mys area, continental volcanics of the late early Eocene age (49 ± 1.9 Ma) are overlain with a distinct unconformity by marine sediments of the middle Eocene Snatol Formation (Gladenkov *et al.*, 1991, Fig. 20). The basal horizons of the volcanic member were not observed.

The Paleocene terrestrial and lagoonal deposits with horizon of volcanic rocks form a thick sequence spreading eastward and southeastward of the Utkholokskii Cape where they are overlain with the distinct angular unconformity by the Snatol Formation (Chelebaeva and Shantser, 1988) (Fig. 3).

The continuous succession of the Paleocene and lower Eocene (?) strata was also studied in the northern part of the zone (Devyatilova, 1980). They are represented by the regressive coastal-continental Chemurnaut Formation, the base of which was not observed. The formation layers are deformed into open although locally steep folds and overlain with a sharp angular unconformity by the middle–upper Eocene volcanics of the Bozhedomka Formation (Shapiro *et al.*, 1987; Fig. III, 3).

In the main territory of Western Kamchatka, the middle Eocene to upper Miocene interval comprises coastal-marine and shelf formations. Their most complete succession can be observed in several sections along the Sea of Okhotsk coast: Tochilino, Mainach, and others. No unconformities were noted in these sections. However, north of Palana, where the middle(?)–

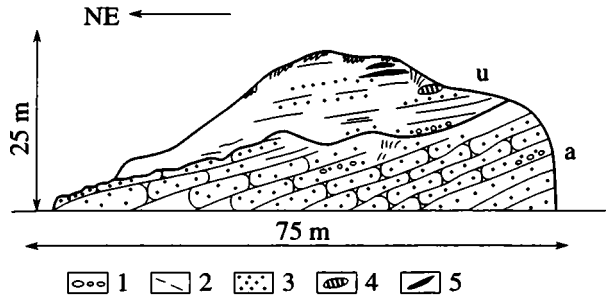

Fig. 2. The angular unconformity between the Paleocene (a, the Anadyrka Formation) and Eocene (u, the Ust'-Anadyrka unit) in the Western Kamchatka coast northeast of the Anadyrka River. 1, conglomerates, gravelstones; 2, claystones; 3, sandstones; 4, carbonate concretions; 5, coaliferous rocks.

upper Eocene section consists of lavas of the Kinkil'skii Mys Formation formed in continental environments, insignificant angular unconformity probably occurs between the latter and underlying middle Eocene deposits of the Ust'-Anadyrka Formation. This unconformity resulted from local volcanic–tectonic movements that immediately preceded eruptions (Gladenkov *et al.*, 1991).

A distinct although not very sharp angular unconformity was recorded at the base of the Pliocene section exposed in the coastal cliffs south of the Utkholok Peninsula, where it rests upon the Miocene units (Sinel'nikova *et al.*, 1979; Fig. 35).

The relationship of Cenozoic and Cretaceous deposits is the most difficult problem. Both Cenozoic and Cretaceous sections are exposed along the single coastal cliffs but they are commonly separated by faults. Previously, angular unconformity between the basal Paleogene and Cretaceous layers was reported from several areas. However, later, the Cretaceous age of the lower unit in some areas, e.g., in the Khairyuzov Cape, Omgon Cape, and the left side of the Palana River, was revised and recently, they are referred to the Eocene (the Snatol time). In other areas (the Pyatibratka Cape and Iichegitun River), they are correlated with the older Paleogene units, but this correlation is not substantiated by reliable dating. Only southward of the Anadyrka River, there is a distinct unconformity between the Paleocene Anadyrka Formation and underlying volcanics and tuffs referred to the Upper Cretaceous Ust'-Anadyrka Formation (Gladenkov *et al.*, 1991; Fig. 15). However, this angular unconformity is insignificant, although the presence of a hiatus at the base of the Paleogene section is beyond a doubt here. From the viewpoint of one of us (A.E. Shantser), its presence in the considered section is highly problematic.

In the territory of Western Kamchatka, the Cenozoic deposits are poorly exposed, and sections comprising large intervals of successive Cenozoic deposits are rarely observed although all the stratigraphic units, from the Paleocene to Pliocene, are recognized. At the same time, there are indirect indications that hiatuses and, probably, insignificant angular unconformities are present at the base of the Utkholok, Il'inka, and Etolon formations in those areas, where the contact with underlying units can be observed. But, as a rule, this is only an assumption based on the transgressive relationship between them and coarse-clastic deposits at the base of these formations rather than on direct observations.

Nevertheless, a sharp angular unconformity between slightly folded Cenozoic sequences and intensely deformed Upper Cretaceous strata was observed in several localities, immediately in outcrops, or was inferred from geological mapping. In some areas (the Medvezhii Range and the Napana River south of the Tigil' Settlement), basal horizons of these sections yielded faunal remains characteristic of the Snatol, Kovachina, and Gakkhin formations. In other areas, mainly located in the axial part of the Tigil' uplift, the base of the Cenozoic section is composed of continental deposits, most of which were referred in the course of geological mapping to the Paleocene–lower Eocene Khulgun (conglomerates) or Napana (coal-bearing deposits) formations (*Geologiya* ..., 1964). Marine sediments conformably overlying these units contain faunal remains of the Snatol or Kovachina formations (middle–upper Eocene). In other words, continuous succession of deposits from the Paleocene to middle Eocene seems to be characteristic of this area,

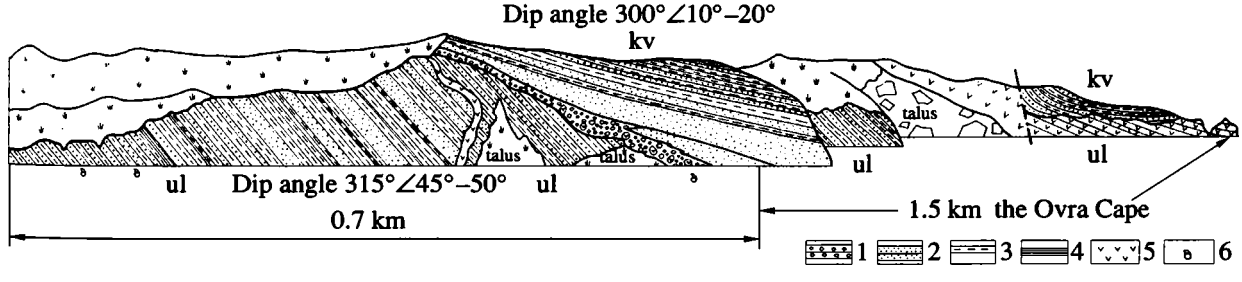

Fig. 3. The angular unconformity between the Paleocene and middle Eocene east of the Utkholok Cape (the sketch picture of the coastal outcrop). 1, middle Eocene basal conglomerates; 2, sandstones; 3, siltstones; 4, claystones; 5, basalts and basaltic andesites; 6, faunal remains; ul, the Ulevene Group; kv, the Snatol and Kovachina formations.

whereas in the coastal sections, this interval shows the sharp angular unconformity. In our opinion, this can be explained by inaccurate dating of basal Cenozoic coarse-clastic continental deposits rather than by a real difference in the tectonic history of the Western Kamchatka coastal and inner sections (which are separated sometimes only by a few dozen kilometers). In most cases, the rocks are dated on the basis of lithological correlation of the deposits being considered with stratotypical sections of the Khulgun and Napana formations in the Snatol and Tigil' river basins rather than on paleontologic characteristics of particular outcrops. Recent studies showed that most continental units in this area contain middle Eocene floral remains and are the age analogues of the marine Snatol Formation (Gladenkov *et al.*, 1991). In our opinion, the conformable boundary between the lower and middle Eocene in Western Kamchatka was proved in none of the areas.

Thus, when considering all of Western Kamchatka, one may note three stratigraphic intervals in the Cenozoic succession of this structural formational zone, in which reliably defined conformable relationships were not observed. These are the Cretaceous–Paleocene, lower–middle Eocene, and Miocene–Pliocene transitions. Distinctly observable angular unconformities correspond to the second and third stratigraphic levels. The pre-Pliocene unconformity is observed only occasionally because of a limited number of exposed Pliocene sections, but the general folded structure of Cenozoic deposits in this subregion, upper Miocene units included, can be related to tectonic movements at the end of the Miocene.

A less certain situation concerns the Cretaceous–Cenozoic boundary, which should be considered more thoroughly with due regard for both direct and indirect evidence for or against the presence of regional angular unconformity at this level. The Upper Cretaceous sequences in Western Kamchatka in axial parts of major anticlines and fault-bounded blocks are represented, on the one hand, by siliceous-terrigenous and volcanogenic deposits (the Santonian–Campanian Irunei Formation and presumably Maestrichtian Ust'-Palana Formation) and, on the other, by marine terrigenous sediments of the upper Omgon Group referred to the Santonian–Campanian. It is assumed that cherty-volcanogenic strata replace upsection the terrigenous sequence or, as southward in the Sredinnyi Range, they are coeval to its upper part and thrust over it. In the latter case, the absence of continuous transitional sections suggests the large overthrust magnitude. Most Cretaceous sections are composed of relatively deep-sea facies. At the same time, the Ust'-Palana Formation was deposited in the vicinity of volcanic islands. In the Utkholok Peninsula, the terrigenous deposits of presuma latest Cretaceous in age contain leaf flora (Chelebaeva and Shantser, 1988).

The deformation style of Upper Cretaceous rocks strongly depends on their composition. Terrigenous sediments are commonly deformed into small steep folds and show intense cleavage and foliation. Sometimes, they are even slightly metamorphozed, though in this case, their reference to the Upper Cretaceous is poorly substantiated. Intense folding is also characteristic of the Irunei Formation though in some areas (the Kinkil'skii Peninsula and Napana and Tigil' river interfluve), Cretaceous strata are only slightly deformed according to Shantser's observations.

Lower Paleogene (Paleocene–lower Eocene) sedimentary deposits of western Kamchatka are uniform in lithology being represented by paralic, often coarse-clastic molassoid rocks. The redeposited Cretaceous rocks are common among the clastic material (Grigorenko, 1981), though it consists in general of cenotypal effusive rocks. In this respect, these deposits are similar to those from basal horizons of the middle Eocene, where they are also represented by paralic coarse-clastic facies often responsible for their erroneous correlations.

Deformations of lower Paleogene strata in Western Kamchatka, which were observed in the Utkholok Peninsula area and in coastal outcrops of the Penzhina Bay, are rather intense, and in the average dip angle values, they are comparable with those in the Upper Cretaceous units. However, small folds, foliation, and cleavage typical of the Omgon Group sections can be observed in Paleogene deposits only along narrow fault zones.

The regular succession of formations, molassoid patterns of the section structure, and somewhat more slight deformations as compared with the Upper Cretaceous sections suggest important events that resulted in the reorganization of general structural patterns and depositional environments in Western Kamchatka. Many features indicate that these events were accompanied by deformation and erosion of Cretaceous deposits, and these very processes should unavoidably result in angular unconformity in sequences. Therefore, the absence of continuous Cretaceous– Paleogene successions is the natural consequence of the regional angular unconformity existing at this level rather than an artifact related to limited exposures of these rocks and the lack of study. At the same time, we are completely aware of the somewhat arbitrary character of this conclusion and further related interpretations.

The Sredinnyi Range zone. The assignment of all the Cenozoic deposits of the Sredinnyi Range to a single structural–formational zone is arbitrary because its northern, central, and southern parts notably differ in the structure of the Cenozoic sections.

The northern part of the Sredinnyi Range, or the Lesnaya uplift, represents an area with abundant Upper Cretaceous deposits overlain by the thin and fragmentary cover of Cenozoic sediments. As in Western Kamchatka, the Upper Cretaceous sections are represented, on the one hand, by relatively deep-water terrigenous deposits that were formed at the foot of the submarine slope (the Lesnaya Group) and, on the other, by

cherty-volcanogenic rocks (the Irunei Formation). The upper age limit of both units is estimated to be the Maestrichtian (Grigor'ev and Shapiro, 1986; Fedorov, 1988). Data on their younger (Eocene) age (Fedorchuk and Izvekov, 1992) should be further confirmed. Both units are intensely deformed and separated by the regional Lesnaya overthrust, along which the Irunei Group is displaced westward (Shantser *et al.*, 1985).

The oldest Cenozoic deposits are represented by continental volcanics occurring in the Lesnaya, Tevi, and Shamanka river basins, where they are referred to the Kinkil' Formation overlying with a sharp angular unconformity the Lesnaya Group and, sometimes, the Irunei Formation. Acidic subvolcanic bodies and large Shamanka granite intrusion genetically related to these effusive rocks intrude the Lesnaya overthrust (Fig. 4). Radiological (K/Ar) age of granites correspond to either the terminal Cretaceous (*Geologicheskaya ...*, 1989) or the initial middle Eocene (Fedorchuk and Izvekov, 1989). The oldest deposits immediately overlying this effusive unit in the Lesnaya uplift compose the Miocene Il'inka Group in the western flank of the Pustaya River depression.

In the southern and eastern Lesnaya uplift, the Cretaceous rocks are overlain with a sharp angular unconformity by the sedimentary member, basal horizons of which are referred to the middle Eocene Snatol Formation, while its upper part is assigned to the upper Eocene (the Kovachina Horizon) and Oligocene (the Utkholok–Viventek Horizon). In the Shamanka River upper course, thick basal horizons of this unit comprise abundant granitoids and hornfels of the Shamanka massif (Shantser *et al.*, 1985). Here, conglomerates are correlated by floral remains with the Kovachina Formation, and this is supported by the fossil fauna from overlying strata, which is characteristic of the Kovachina and Amanin formations.

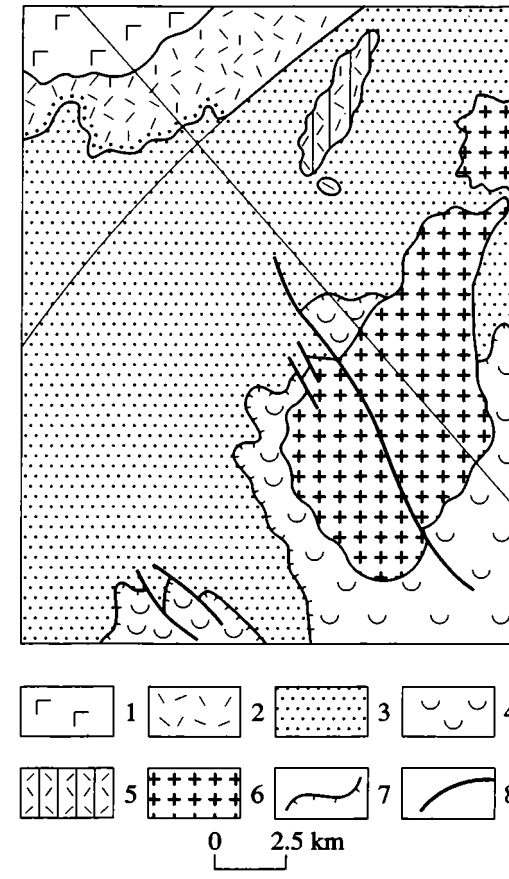

Fig. 4. Geological relationships of Cretaceous and Paleogene rock complexes near the Shamanka granite massif of the Lesnaya uplift. 1, 2, Paleogene, the Kinkil' Formation: 1, the upper part (basalts and andesites), 2, the lower part (dacites and rhyolites); 3, 4, Upper Cretaceous: 3, the Lesnaya Group (claystones and sandstones), 4, the Irunei Formation (tuffs, cherts, and claystones); 5, subvolcanic rhyolite bodies; 6, granites; 7, the Lesnaya overthrust; 8, steep-dipping faults.

The deposition of this unit was evidently preceded by the two-stage erosion of the Lesnaya uplift. The first erosional event was connected with the formation of the uplift and general folding that resulted in the angular unconformity under the Kinkil' Formation. During the second stage, erosion affected both the latter formation and its basement, including volcanic center zones. Uncertain dating of the Kinkil' Formation does not permit the age of these events to be determined unambiguously. If we correlate it with the Kinkil'skii Mys Formation northward of the Palana Settlement, as it is commonly done, the stratigraphic hiatus corresponding to the first erosional event will be the Paleocene–first half of the Eocene in age, and, thus, more precise dating of folding responsible for the angular unconformity at the base of the Kinkil' Formation is impossible. In this case, the second erosional event in the Lesnaya uplift should be referred to the terminal middle Eocene (the boundary between the Snatol and Kovachina formations), but this dating conflicts with the structure of the Eocene sections in framing structures, where this level is marked by basin deepening. If, however, the Kinkil' Formation of the Lesnaya uplift is correlated with Paleocene–lower Eocene effusive rocks of Western Kamchatka (Kakhtanin Cape, Utkholok Peninsula), these two stages of deep erosion will be coeval with the formation stages of angular unconformities here: at the Cretaceous–Paleocene boundary and in the initial middle Eocene.

Unlike Western Kamchatka, the northern Sredinnyi Range lacks Cenozoic sections encompassing large stratigraphic intervals. Nevertheless, conformable relationships between several formations in the interval from the middle Eocene Snatol Formation to the lower Miocene Kuluven Formation (*Geologicheskaya ...*, 1989) were observed there. The middle Miocene Il'inka and Etolon formations commonly rest upon older Cenozoic units with a hiatus, and insignificant angular unconformities were observed only in those areas where they overlie the Kinkil' Formation.

In the eastern slope of the Lesnaya uplift, the axial part of the Sredinnyi Range, continental effusive rocks that were previously referred to the lower–middle Miocene Berezovka and Miocene–Pliocene Alnei formations are widespread alongside the sedimentary Cenozoic units. Regional angular unconformities were previously thought to be present at the base of these formations. However, later geological mapping revealed gradual transition between the Il'inka Formation and younger volcanic rocks. Angular unconformities are present, along with gradual transitions, within the volcanic sequence and are most probably of local, volcanic–tectonic origin. Angular unconformity of a regional character was recorded only at the base of the uppermost Piocene–Quaternary volcanic complex that lies horizontally almost everywhere.

The southern Sredinnyi Range, or the Malkin uplift is characterized by the wide development of pre-Cretaceous (metamorphic) and Cretaceous rocks, while Cenozoic rocks of patchy distribution occur only in the flanks of this uplift. As in the north, the Upper Cretaceous sections here are composed of terrigenous rocks mostly distributed in the western slope of the range (the Kikhchik Group) and cherty–volcanogenic deposits predominant in its eastern slope (the Irunei and Kirganik formations). The youngest terrigenous and cherty–volcanogenic units are Maestrichtian and, probably, Danian in age (Pozdeev and Petrina, 1984).

The oldest Cenozoic rocks in the western slope of the southern part of the range are represented by continental volcanics of the Cherepanova Formation correlative, based on geochronological age estimates, to the Paleocene (oral communication by D.I. Babushkin). Their contact with underlying Cretaceous rocks was not observed, but the relatively flat occurrence of volcanics is in strong contrast to the complicated structure of the Cretaceous sequences, the fact unambiguously indicating the existence of the angular unconformity at the base of the Cherepanova Formation. The younger units are represented by fragments of the Eocene, Oligocene, and Miocene formations unconformably overlying the Cretaceous strata. The contacts between these formations are rarely observed, and this prevents defining the levels corresponding to probable intra-Cenozoic angular unconformities.

In the eastern slope of the Malkin uplift, the oldest Cenozoic sedimentary rocks are assigned, based on floral and molluscan evidence, to the Snatol Formation, whose contact with the Cretaceous units is poorly exposed. In the northern part of the uplift, the Cretaceous rocks are overlain with angular unconformity by volcanics united into the Miocene Berezovka Formation, whose more precise dating is thus far not available.

The central Sredinnyi Range is characterized by the almost universal distribution of Pliocene–Quaternary volcanics, among which pre-Pliocene rocks are exposed in deep incisions or separate uplifted blocks. The oldest pre-Pliocene rocks reported by Yu.V. Zhegalov as composing the lower part of the so-called Anavgai Group are referred to the Oligocene. They are distributed in the eastern slope of the range along right tributaries of the Elovka River and are mainly represented by effusive rocks of acidic and intermediate composition. More widespread are middle Miocene extrusions and tuffs of the Kavavlin Formation (Valov *et al.*, 1978).

Summarizing all the data on the entire structural–formational zone of the Sredinnyi Range, we can see that the Cenozoic succession reveals two intervals, within which no gradual transitions between the units were observed, and which could correspond to deformation episodes responsible for most of the angular unconformities observed. The upper one corresponds to the interval between the middle Miocene and Pliocene, whereas the lower, wider one encompasses the Paleocene and lower Eocene. Such a long span of the lower interval is conditioned by the absence of reliably defined Paleocene and lower Eocene deposits in the Sredinnyi Range. There are grounds to assume that the Kinkil' Formation of the Lesnaya uplift and the Cherepanova Formation in the southern Sredinnyi Range correspond to this interval. In this case, regional unconformities corresponding to the Cretaceous–Paleogene transition and basal lower Eocene could be inferred in the Sredinnyi Range as in Western Kamchatka. If these poorly dated units are close in age to the Snatol Formation (which is not inconceivable), the question of the age of deformations that resulted in the pre-middle Eocene unconformity in the Sredinnyi Range will remain unanswered.

The spatial closeness of both the Upper Cretaceous and Paleogene rock complexes of Western Kamchatka and the Sredinnyi Range suggests that deformation events in both zones occurred at the same levels: at the Cretaceous–Paleogene boundary and in the initial middle Eocene.

The Central Kamchatka trough. The Paleogene–Neogene deposits of the Central Kamchatka trough are poorly studied because this subregion is almost completely covered by Quaternary sediments or by the sea. In the axial part of the trough, the Cenozoic deposits are exposed only in the Elovka and Ozernaya river watershed area where their sequence is also insufficiently studied. In the southern part of the trough, both sides are mostly composed of Cretaceous rocks. In its structure, the Cenozoic sequence in the western flank of the trough is similar to that of the Sredinnyi Range. The pre-Snatol deposits are not exposed here. The only well-studied Cenozoic section in Kamchatka that can be considered as a type section for the Central Kamchatka trough was described in the western part of the Karaginskii Island (Gladenkov *et al.*, 1992).

This island is divided by the zone of major linear faults into two parts. The stratigraphy of its southeastern part is similar to that of the eastern ranges of Kamchatka. In the northwestern part of the island, the

section begins with tuffaceous–sedimentary deposits of the middle–upper Eocene Mys Tons Formation, which are followed upward by sedimentary, less commonly tuffaceous Oligocene, Miocene, and Pliocene units. The sequence lacks angular unconformities, though small hiatuses were recorded at the base of the Il'khatun (Oligocene), Mys Ploskii (top layers of the middle Miocene), Yunyun'vayam (upper Miocene), and Limimtevayam (Pliocene) formations. In structural terms, the northwestern Karaginskii Island forms the monocline complicated by small flat flexures. Near the faults, which bound the eastern part of the island, small nappes and folds with steep dip angles occur.

The base of the Mys Tons Formation was not observed, but the transgressive contact between the Mys Ploskii Formation and underlying steep-dipping Cretaceous (Maestrichtian) strata is clearly seen south of the Severnaya River mouth in the eastern part of the island (Fig. 5). This distinct angular unconformity observable against the background of conformable relationships of the Mys Ploskii Formation and underlying deposits in the northwestern part of the island suggests that strong deformations occurred during the interval between the Maestrichtian and middle Eocene.

In the Il'pinskii Peninsula, one of the stratotype sections of the Paleogene in the Koryak–Kamchatka region, which was subdivided into relatively fine units based on calcareous microplankton (Volobueva *et al.*, 1994), is commonly considered to represent a reference section for Paleogene deposits of the Central Kamchatka trough. It is featured by the lack of angular unconformities in the continuous succession from the uppermost Cretaceous to Oligocene. However, the parallel unconformity occurs at the Cretaceous–Paleogene boundary being marked by conglomerates. Traces of erosion (coarse-clastic members of the Kilakirnun Formation within fine-grained terrigenous deposits) are also observed in the middle Eocene interval. Unconformity and a distinct erosional surface seem to be present only at the base of the middle–upper Miocene continental Korf Group in the Korf Bay area (Gladenkov *et al.*, 1987).

Due to the lack of angular unconformities in the interval from the Cretaceous and middle Eocene, this section of the Il'pinskii Pininsula differs from most Kamchatka sections. Angular unconformities were also not observed in the adjacent northeastern areas of the Olyutor zone of the Koryak Highland. In the latter area, the Cretaceous and Paleocene deposits form a continuous succession, whereas sections with gradual transition from the lower to middle Eocene were not recorded. Therefore, this time interval is the most favorable for the occurrence of intense deformations characteristic of the Upper Cretaceous and Paleocene–lower Eocene sequences of the Olyutor zone. In this case, the conformable relationship of lower and middle Eocene strata in the Il'pinskii Peninsula is a local phenomenon related to the lack of post-folding uplift and

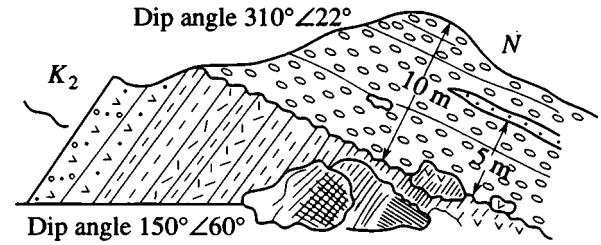

Fig. 5. The angular unconformity between Cretaceous and Neogene units in the northern Karaginskii Island (the Severnaya River mouth). For the legend see Fig. 2.

erosion at the beginning of the middle Eocene in this area. Yet, one cannot exclude that deformations in the Olyutor zone, the Il'pinskii Peninsula included, have been developing asynchronously with respect to those in Kamchatka.

Zone of eastern ranges. Cenozoic deposits in this zone occupy different structural positions in different areas. In the Tumrok Range and axial parts of the Kumroch and Valaginskii ranges and their western slopes, Cenozoic sections of the pre-middle Eocene age are composed of flysch deposits of the Drozdovskaya and Tal'nik formations. The latter formation yielded the Paleocene–lower Eocene planktonic foraminifer assemblage (Bakhteev *et al.*, 1994). The formations conformably and with gradual transition replace volcanogenic deposits mostly referred to the Upper Cretaceous and, probably, basal Paleocene (Khapitsa Formation, Valaginskii Group). The Upper Cretaceous–lower Paleogene flysch is deformed into a series of steep folds and nappes, sometimes, of distinct southeastern vergence.

In the eastern slopes of the Kumroch and Valaginskii ranges, the lower part of the Paleogene sequence is referred to the Vetlovaya Formation of variable composition, which forms a series of nappes of eastern vergence. This is a relatively deep-water, predominantly clayey unit with interbeds of siliceous rocks, sandstones, gravelstones, tuffs, and basaltic flows in different parts of the section (Shapiro *et al.*, 1984). Neither the base nor the top of the unit were observed. Moreover, the complicated tectonic structure prevents an unambiguous interpretation of stratal succession within it. Radiolarians and planktonic foraminifers collected at different levels of the Vetlovaya Formation section were assigned to the Paleocene and basal Eocene (Tsukanov, 1991; Bakhteev *et al.*, 1994). Analogues of this unit compose the southeastern Karaginskii Island (Chekhovich *et al.*, 1990).

The western boundary of the Vetlovaya Formation distribution area corresponds to the major Vetlovskii thrust-fault, along which Cretaceous and lower Paleogene deposits of the axial part of the range are thrusted southeastward. In the Valaginskii Range, this thrust-fault is accompanied by a zone of thick sedimentary melange (Bakhteev *et al.*, 1994). The eastern boundary

of the zone of eastern ranges corresponds either to the thrust-fault at a joint with the Tyushevka depression (the Kumroch Range), or the nappe composed of younger rocks. Thus, by the composition of the pre-middle Eocene sections, the zone of eastern ranges is distinctly subdivided by the Vetlovskii thrust-fault into two linear subzones.

The lower Eocene–Miocene deposits in the zone of eastern ranges are mainly confined to two transverse depressions. The first of them is located in the southern Valaginskii Range. Middle Eocene deposits were observed here in two small areas: in the Konstantinovskaya and Kornilovskaya river valleys. In the first of these areas, sharp unconformity was recorded between paleontologically dated middle Eocene terrigenous shelf deposits and underlying sedimentary melange of the Vetlovaya overthrust (Bakhteev *et al.*, 1994). The Eocene deposits, in their turn, are overlain by Miocene sediments, but the contact between them was not observed and, thus, the angular unconformity cannot be proved. The upper Miocene deposits conformably rest upon the lower Miocene strata and are overlain with angular unconformity by Pliocene volcanics.

In the Kornilovskaya River valley, the middle Eocene is represented by the lowermost part of the thick sandy-clayey transgressive–regressive sequence, whose different horizons overlie the Vetlovaya Formation with angular unconformity. The top layers of this sequence referred to the middle Eocene are overlain without angular unconformity, but locally, probably, above the erosinal surface by the middle–upper Miocene predominantly conglomerate unit, which, in turn, is unconformably overlain by Pliocene volcanics (the Shchapina Formation and Tumrok Complex). Pliocene volcanics are widespread in the esastern ranges and commonly show insignificant deformations with preserved initial dip angles of strata.

The Ozernoi Peninsula, with northern piedmonts of the Kumroch Range and depression between them, is another area of wide distribution of middle Eocene–Miocene deposits in the zone of eastern ranges. The oldest strata of the Cenozoic section here are considered to be the early middle Eocene in age and represented by the Konskaya Formation in the Ozernoi Peninsula (Litvinov *et al.*, 1990) and Pravyi Kroton Formation in the Kumroch Range (data by M.E. Boyarinova). In both the peninsula and range, middle Eocene sections are conformably overlain by upper Eocene–middle Miocene. Together with middle Eocene deposits they form transgressive sequence, whose different horizons overlie with a sharp unconformity the Cretaceous deposits. The middle part of the middle Miocene section is marked by an erosional surface, but no angular unconformities within the Cenozoic section were recorded. In the Ozernoi Peninsula, angular unconformity is present only at the base of almost undeformed Pliocene effusive rocks.

Thus, both the northern and southern parts of the zone of eastern ranges show continuous successions from the uppermost Creatacous to the lower Eocene and from the middle Eocene to the upper Miocene. Absent are sections with conformable relationships at two levels: (1) between the lower and middle Eocene and (2) between the Miocene and Pliocene. In other words, deformations responsible for the sharp angular unconformities might have occurred only in transition intervals from the early to middle Eocene and from the Miocene to Pliocene.

The Tyushevka trough. The Tyushevka trough is commonly considered to be confined to the relatively narrow and very unevenly exposed band of thick, intensely deformed terrigenous upper Paleogene–Miocene deposits separating eastern peninsulas (Shipunskii, Kronotskii, and Kamchatskii Mys) with the predominant Cretaceous and lower Paleogene rock complexes from the rest of Kamchatka. At the latitude of the Shipunskii Peninsula, their sequences are essentially composed of several narrow thrust nappes. At the latitude of the Kamchatskii Mys Peninsula, they also form a narrow band bounded by overthrusted lower Paleogene rocks of the Kumroch Range in the northwest and overlain by the Quaternary sediments in the southeast. Only in the Kronotskii isthmus area, the rocks of the trough are exposed almost universally. The oldest deposits here are represented by sandy-clayey members referred, according to Bakhteev's data, to the upper half of the Eocene. They are overlain without the angular unconformity but probably with erosion marks by the siliceous-clayey Oligocene–lower Miocene (?) Chazhma Formation. The lower–middle Miocene interval of the section corresponds to the flyschoid Tyushevka Group (Arsanov, 1978). The presence of an upper Miocene strata in this so far insufficiently studied section is not proved, but is probable. The total thickness of the Cenozoic sequence in the Tyshevka trough exceeds 4000 m. The sequence is deformed and consists of several nappes separated by thrusts, the easternmost of which is known as the Grechishkin thrust. This entire structural system is overlain with very sharp angular unconformity by almost undeformed Pliocene volcanics (Fig. 6).

Northward, in the Ust'-Kamchatsk area, where only small fragments of the Tyushevka trough are exposed, the Oligocene–Miocene section lacks the unconformity marks. It is noteworthy, however, that conglomerates at the base of the section, which are arbitrarily referred to the Oligocene, largely consist of rock clasts of the Paleocene Tarkhovskii Formation of the Kamchatskii Mys Peninsula. This suggests pre-Oligocene (?) deep erosion of the peninsula zone (or its northern part).

Thus, the Tyushevka trough is evidently featured by the continuous deposit succession from the middle Eocene to middle Miocene. At the same time, there is a hiatus between the middle Miocene and Pliocene, and a sharp angular unconformity at the base of the

Pliocene, which corresponds, most likely, to the folding at the Miocene–Pliocene boundary.

The zone of eastern peninsulas comprises (from the north southward) the Kamchatskii Mys, Kronotskii, and Shipunskii peninsulas. The thickest and most complete lower Paleogene section in this zone was described in the northern Kamchatskii Mys Peninsula, where the volcanogenic-sedimentary Stolbovskii Group encompasses the interval from the Maestrichtian to the basal upper Eocene (Ben'yamovskii *et al.*, 1992). Angular unconformities were not observed in this section, nevertheless, the cryptic hiatus is probably present at the lower–middle Eocene boundary, which is marked by the absence of some faunal zones from the section and by conglomerate horizons. The base of the formation is not exposed, and its relationship to pre-Maestrichtian strata (the Afrika Group) is unknown. The Stolbovskii Group layers are deformed into large folds and are overlain by Pliocene–Quaternary sediments of the Ol'khovaya Formation. The aforementioned rock clasts from the lower part of the Stolbovskii Group (the Tarkhovskii Formation) occur in Oligocene (?) conglomerates of the Tyushevka and are the only indirect evidence for the folding age.

In the southern part of the peninsula, where intensely deformed Cretaceous rock complexes dominate, there are several small blocks and tectonic nappes composed of Miocene sediments. A significantly gentler dipping of the Ol'khovskaya Formation suggests a deformation event at the end of the Miocene–beginning of the Pliocene. At the same time, the Ol'khovskaya Formation proper locally shows intense deformations reflecting the active tectonics of the block located at the joint of two island arcs.

The stratigraphy of the Upper Cretaceous and lower Paleogene deposits in the Kronotskii Peninsula lacks unambiguous interpretation so far. The Mys Kamenistyi Formation (Coniacian–Danian) and the lower Paleogene Kronotskii Group overlying the latter and subdivided into the Kubovaya and Kozlovaya formations have been defined there for a long time (Sadreev and Dolmatov, 1965). The Mys Kamenistyi Formation was subdivided into two members: the lower one with Coniacian–Campanian radiolarians and the upper one, which yielded radiolarians of the Upper Cretaceous–lower Paleocene in one locality (Tsukanov, 1991). These members are separated by faults and serpentinite melange zones. Recent determinations of planktonic foraminifers and nannofossils revealed the Eocene age of the upper unit (Ben'yamovskii, 1992). The lower, Kubovaya Formation of the Kronotskii Group, which was previously referred to the Paleocene (Serova, 1966) correlates partly with the uppermost lower Eocene and mainly with the middle interval of this stage. The Kubovaya Formation has stratigraphic contact only with the upper member of the Mys Kamenistyi Formation, and this (with consideration of recent age determinations) characterizes the rock relationships only within the Paleogene, and, thus, the character of Cretaceous–Paleogene boundary remains unknown in this area. The presence of angular unconformity at the base of the Kubovaya Formation cannot be considered as proved. In those outcrops, where this unconformity was reported to be present (Tsukanov, 1991), the lower part of the section is represented by pillow basalts unsuitable for precise measurements of their dip and strike. The presence of ultramafic rock clasts in the Kubovaya Formation conglomerates also cannot serve as a decisive argument in favor of the unconformity existence at its base.

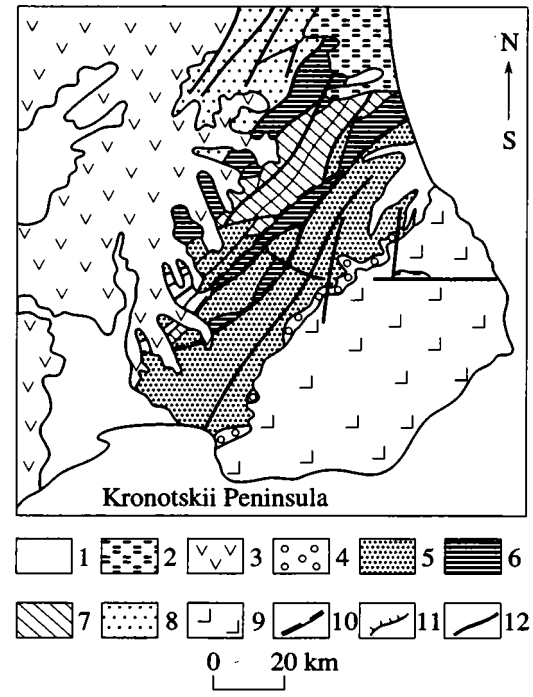

Fig. 6. Scheme of geological structure of the Kronotskii Isthmus. 1, loose Quaternary sediments; 2, Pliocene sedimentary deposits; 3, Pliocene–Quaternary volcanics; 4, the Rakitinskaya Formation; 5, the Tyushevka Group; 6, the Chazhma Formation; 7, the Tundra Formation (Eocene); 8, 9, Cretaceous and lower Paleogene deposits: 8, the eastern ranges zone, 9, the Kronotskii Peninsula; 10, the Grechishkin overthrust zone; 11, the overthrust at the joint of the eastern ranges zone and Tyshevka trough; 12, other dislocations.

The noteworthy feature of the Kronotskii Peninsula section is the stable and peculiar geochemical characteristics of basalts in the interval from the uppermost Cretaceous (the lower member of Mys Kamenistyi Formation) to the uppermost middle Eocene (the Kozlovaya Formation) (Khubunaya, 1987). This can be considered as an argument against significant tectonic reorganizations in the considered area at that time. Nevertheless, the erosional surface at the base of Kubovaya Formation and the absence of paleontologically substantiated Paleocene and lower Eocene deposits from the Kronotskii Peninsula sections allow the hiatus

related to tectonic deformations to be suggested at this level.

Erosional surface and locally insignificant angular unconformities are commonly observed at the base of the Kozlovaya Formation overlying the Kubovaya Formation.

In the western slope of the mountaneous massif of the Kronotskii Peninsula, at the border with a Tyushevka trough, the Kozlovaya Formation is overlain with the distinct angular unconformity of thin terrigenous sequence wedging out eastward, the basal part of which incorporating coal-bearing beds, sandstones with coquinas, and siliceous-glauconote rocks was distinguished as the Rakitinskaya Formation. Mollusks, benthic foraminifers, and diatom algae from this formation allow it to be correlated with the basal part of the Kavran Group of Western Kamchatka (middle Miocene). The overlying terrigenous unit was previously correlated, based on lithology and molluscan fauna, with the lower Miocene Tyushevka Group of the Tyushevka trough. The lithologic analogues of siliceous-glauconite layers of the Rakitinskaya Formation were penetrated by boreholes under the Tyushevka flysch in the Konusnaya River basin. Based on these observations, Arsanov (1978) suggested the pre-Tyushevka (Oligocene) age of the Rakitinskaya Formation. In any case, the existence of angular unconformity between the Eocene and middle Miocene in this area is beyond a doubt, although the precise age of related tectonic movements is yet to be determined. It is not inconceivable that these very movements formed overthrusts and serpentinite melange in the Upper Cretaceous and lower Paleogene sections of the eastern Kronotskii Peninsula.

In its structural patterns, the lower Paleogene sequence of the Shipunskii Pennsula is similar to that of the Kronotskii Peninsula. It is also subdivided into the Kubovaya and Kozlovaya formations. The younger Cenozoic deposits are of a small thickness and fragmentary; however, according to oral communication by A.M. Litvinov, the angular unconformity was observed at the base of Pliocene marine sediments overlying Miocene deposits.

The comparison of the structures of the Kamchatskii Mys and Kronotskii peninsulas reveals their essential difference. The continuous succession of strata from the Maestrichtian to upper Eocene is characteristic of the former, whereas a large hiatus between the Campanian and topmost lower Eocene seems to be present in the latter. Probably, this reflects the objective differences in the Late Cretacous–early Cenozoic evolution of these two areas, but it is not less probable that overthrusts and abundant effusive rocks impede the detection of missing parts of the section in the Kronotskii Peninsula. The post-middle Eocene evolution of both peninsulas is similar, because since that time they represented uplifted areas, where deposited sequences were reduced and fragmentary, i.e., unfavorable for correlation with respect to their hiatuses and unconformities. Nevertheless, the pre-Pliocene unconformity is documented in both the Kamchatskii Mys and Shipunskii peninsulas.

CONCLUSION

The temporal distribution of unconformities. The data presented here allow us to draw some general conclusions on the temporal and spatial distribution of angular unconformities in the Cenozoic of Kamchatka. Figure 7 shows that deformations responsible for major unconformities occurred not randomly, but were confined first and foremost to three relatively short time intervals: the Cretaceous–Paleogene transition, earliest middle Eocene, and Miocene–Pliocene boundary.

During the first time interval, deformations affected the southern part of the peninsula (Western Kamchatka and the Sreddinnyi Range), where sections with gradual Cretaceous to Paleogene transition are absent. This level is marked by regional change in formations and intensity of rock deformations; sometimes, stratigraphic unonformities can be observed here directly in outcrops (the Anadyrka River basin). Still, indubitable angular unconformities between the Cretaceous and lower Palegene were not documented immediately in outcrops, and this introduces a certain ambiguity in conclusions on the regional character of deformations at this level. The progress in solving this problem mainly depends on precise dating of several stratigraphic units, particularly of the Kinkil' Formation in the Lesnaya uplift and Cherepanova Formation in the southern Sreddinnyi Range.

In Eastern Kamchatka, a hiatus at this level is possible only in the Kronotskii Peninsula area, where paleontologic evidence for the presence of Maestrichtian, Paleocene, and the lowermost Eocene beds are very doubtful. Still, no changes in the formation composition and degree of rock deformations were observed here that indicates the lack of a sharp unconformity between the Cretaceous and Paleogene.

Deformations of the second phase corresponding to the lower middle Eocene occurred in Kamchatka to a varying extent almost universally. The sections, which lack the observable hiatus or show gradual transition from the lower to middle Eocene, were recorded only in the Il'pinskii, Kamchatskii Mys, and Kronotskii peninsulas. In the first two areas, however, erosional surfaces are present in the middle part of the middle Eocene, and in the last one, a hiatus seems to be present in the topmost lower Eocene. The sharp angular unconformity between the lower and middle Eocene was reliably documented in zones of Western Kamchatka and eastern ranges, and forcible though indirect evidence favoring the middle Eocene deformations responsible for angular unconformities were obtained from the Sreddinnyi Range and eastern Central Kamchatka trough (the Karaginskii Island).

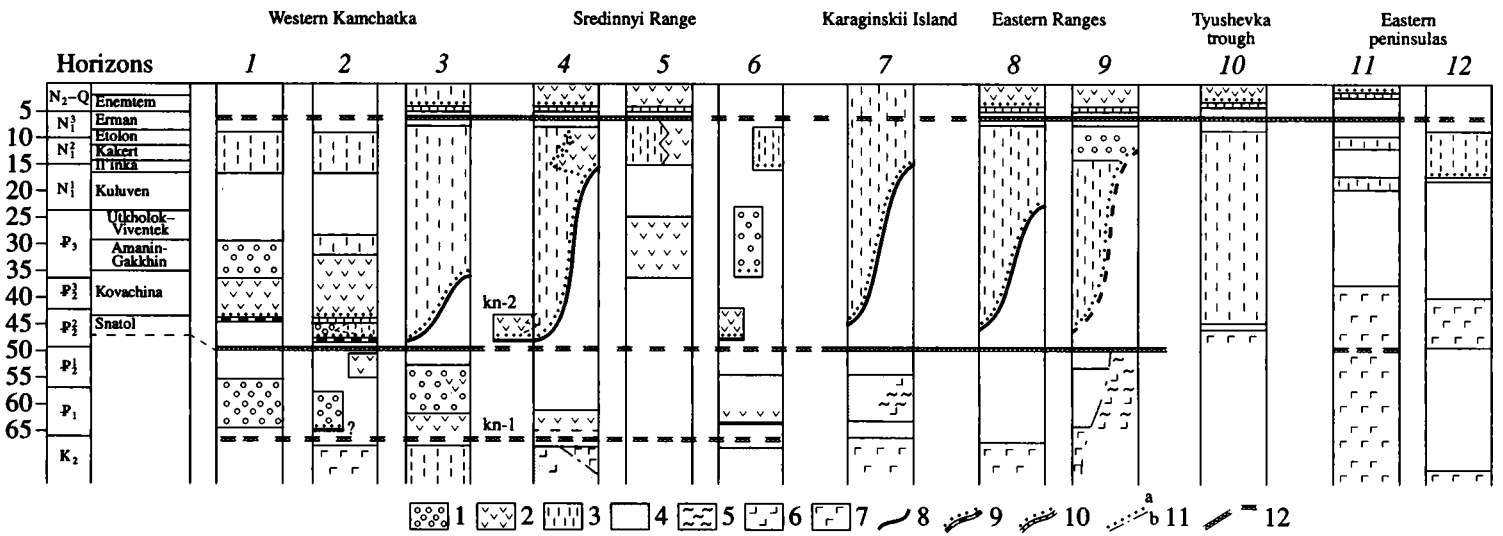

Fig. 7. Position of angular unconformities in Cenozoic sections of Kamchatka: 1, continental and paralic deposits; 2, subaerial volcanics; 3, shelf, mainly terrigenous deposits; 4, relatively deep-water terrigenous deposits (predominantly flysch); 5, cherty-clayey tuffaceous deposits; 6, suboceanic basalts; 7, effusive-tuffaceous marine deposits with island-arc volcanics; 8–10, angular unconformities in Cenozoic sequences above the Cretaceous (8), Paleocene and lower Eocene (9), and middle Eocene–Miocene (10) units; 11, boundaries of coeval formations: lithological (a) and tectonic (b); 12, stratigraphic levels corresponding to tectonic deformations responsible for major angular unconformities in the Cenozoic deposits (descrete line is drawn in those sections where unconformities were not observed or poorly dated). kn-1 and kn-2, two alternative stratigraphic position of the Kinkil' Formation in the northern Sredinnyi Range. Column numbers correspond to numbers in Fig. 1.

Sections: (*1*) Eastern coast of the Penzhina Gulf; (*2*) the Palana Settlement area; (*3*) the Utkholok Peninsula; (*4*) the Lesnaya uplift; (*5*) eastern slope of the central Sredinnyi Range; (*6*) the southern Sredinnyi Range; (*7*) the Karaginskii Island; (*8*) the Ozernoi Peninsula (after Litvinov *et al.*, 1990); (*9*) the Valaginskii Range, southern part; (*10*) the Tyushevka trough; (*11*) the Kamchatskii Mys Peninsula; (*12*) the Kronotskii Peninsula.

The long interval from the mid-Eocene to terminal Miocene is a time when regional angular unconformities were not forming in the Cenozoic sections of Kamchatka, though slow and intermittent sea transgression toward the land that was formed in the mid-Eocene time resulted in the clearly observable angular unconformity at the base of the upper Eocene–Miocene sections in those areas, where they are underlain by the lower Paleocene, Cretaceous, and older deposits. There are also exceptions to this rule. Some of them concern unconformities inside volcanic sequences or at their base, as, for instance, at the base of the Kinkil'skii Mys Formation in Western Kamchatka. Other exceptions are related to the local deformations, e.g., the unconformity at the base of the Rakitinskaya Formation in the Kronotskii Peninsula. It is not inconceivable that in the other areas of Kamchatka, the uplift stage that resulted in a hiatus at the base of the middle Miocene corresponds to this event.

In the terminal Miocene, the Kamchatka Peninsula again experienced regional tectonic movements that resulted in angular unconformities observable in all the structural-formational zones of the peninsula. The only section of Kamchatka with conformable structural relationship between the Miocene and Pliocene strata is that of the Karaginskii Island in the eastern flank of the Central Kamchatka trough. However, these observations were obtained from a single small outcrop and cannot serve as an absolutely reliable argument favoring the absence of pre-Pliocene deformations in this part of the considered region.

Tectonic deformations also occurred in Kamchatka in later periods (the Pliocene and mid-Quaternary), but in this paper, they are not considered.

Structural position of unconformities. The spatial distribution of deformations responsible for the formation of angular unconformities in the Cenozoic sequence of Kamchatka reveals regular patterns. Deformation of the first phase affected the western part of the peninsula, whereas those of every subsequent phase progressively pierced further eastward and also occurred in those areas, which experienced deformations during the earlier phases. It should be noted, however, that most intense deformations and, accordingly, sharpest angular unconformities of every phase are observed in those zones, where deformations of the previous phase were not documented. This is no surprise because the considered unconformities are related, as it was already noted in the Introduction to the paper, to certain types of deformations connected with the folding of sedimentary-volcanogenic deposits of the fold region. Every folding phase consolidates the crust, and thus impedes its subsequent deformation. Such deformations commonly do not evenly cover the entire fold system, but are concentrated along relatively narrow zones, beyond which they noticeably weaken.

In this connection, it should be emphasized that the area with the angular unconformity between the Cretaceous and lower Paleogene deposits corresponds, to a first approximation, with the area of the distribution of intensely folded Cretaceous deposits in both sides of the Lesnaya uplift. The position of borders of this fold-thrust zone is rather arbitrary, because in the west, it is cut by the Sea of Okhotsk coast, and the age of folding in the Cretaceous sections on the eastern slope of the Sredinnyi Range is thus far not known. It is clear, however, that the Vostochnyi Range does not belong to this zone because the intense folding occurred here much later.

Though the unconformities of the next middle Eocene level are more widespread (from the western coast to eastern ranges), the most distinctive structural dissimilarity between the middle Eocene–Miocene sequences and underlying lower Paleogene units is characteristic of the Vetlovaya overthrust zone in Eastern Kamchatka, where Cretaceous and lower Paleogene strata are deformed into steep tectonic nappes and compressed folds.

The pre-Pliocene unconformity is most-pronounced in the Grechishkin thrust zone of the Tyushevka trough, where the middle Eocene–Miocene sections show very intense deformations. In the rest of Kamchatka, the structure of these rock complexes is essentially less complicated, and the unconformity between the Pliocene and older Cenozoic units is less pronounced.

In summary, we believe that the formation of regional angular unconformities in the Cenozoic deposits of Kamchatka and generation of three major fold-thrust zones (or fold systems) in the region were governed by the same deformation processes.

The analysis of geodynamic factors responsible for these processes and, subsequently, the nature of the considered angular unconformities is a large independent problem and is beyond the scope of the present work. The other line of further investigation concerns the comparison of data on angular unconformities of Kamchatka, first, with data on other geologic events in the region under study and, second, with data on angular unconformities in other regions of both the North Pacific framing and beyond its limits.

Reviewer M.A. Akhmet'ev

REFERENCES

Arsanov, A.S., The Attempt of Natural Stratigraphic Subdivision of the Oligocene–Miocene Section in the Kronotskii Peninsula Area of Eastern Kamchatka, in *Problemy stratigrafii i istoricheskoi geologii* (Problems of Stratigraphy and Historical Geology), Moscow: Mosk. Gos. Univ., 1978, pp. 181–191.

Bakhteev, M.K., Ben'yamovskii, V.N., Bragin, N.Yu., *et al.*, New Data on Mesozoic–Cenozoic Stratigraphy of Eastern Kamchatka (Valaginskii Range), *Stratigr. Geol. Korrellyatsiya*, 1994, vol. 2, no. 6, pp. 77–84.

Ben'yamovskii, V.N., Fregatova, N.A., Spirina, L.V., *et al.*, Zonation of Planktonic and Benthic Foraminifers in the

Paleogene of Eastern Kamchatka, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1992, no. 1, pp. 100–113.

Chekhovich, V.D., Bogdanov, N.A., Kravchenko-Berezhnoi, I.R., *et al.*, *Geologiya zapadnoi chasti Beringovomor'ya* (Geology of the Western Bering Sea Region), Moscow: Nauka, 1990.

Chelebaeva, A.I. and Shantser, A.E., New Data on the Early Paleogene of Western Kamchatka, in *Litologiya i stratigrafiya mezozoya i kainozoya vostochnykh raionov SSSR* (Lithology and Stratigraphy of the Mesozoic and Cenozoic in the Eastern Regions of the USSR), Moscow: Nauka, 1988, pp. 135–149.

Devyatilova, A.D., Biostratigraphy and Correlation of Marine Eocene Deposits of the Eastern Coast of the Penzhina Gulf, in *Materialy po geologii i poleznym iskopaemym Severo-Vostoka SSSR* (Materials on Geology and Mineral Resources of the Northeastern USSR), 1980, no 25, pp. 22–30.

Fedorchuk, A.V. and Izvekov, I.N., New Data on Structure of the Northern Sredinnyi Range of Kamchatka, *Izv. Ros. Akad. Nauk., Ser. Geol..*, 1992, no. 12, pp. 147–151.

Fedorov, P.I., Geochemistry and Petrology of Upper Cretaceous Volcanics of the Kamchatka Isthmus, *Geokhimiya*, 1988, no. 11, pp. 1627–1637.

Geologicheskaya karta SSSR, Masshtab 1 : 1 000 000 (novaya seriya). List 0-57 (58)—Palana. Ob'yasnitel'naya zapiska (Geological Map of the USSR. Scale 1: 1 000 000 (new series). Sheet 0-57 (58)—Palana. The Explanatory Notes), Leningrad: Vses. Inst. Geol., 1989.

Geologiya SSSR: Kamchatka, Kuril'skie i Komandorskie ostrova. Ch. 1. Geologicheskoe opisanie (Geology of the USSR: Kamchatka, Kuril and Komandor Islands. Part 1. Geological Description.), Moscow: Nedra, 1964, vol. 31.

Gladenkov, Yu.B., Barinov, K.B., Basilyan, A.E., *et al.*, *Detal'noe raschlenenie neogena Kamchatki* (Fine Subdivision of the Neogene in Kamchatka), Moscow: Nauka, 1992.

Gladenkov, Yu.B., Brattseva, G.M., and Sinel'nikova, V.N., Marine Cenozoic Deposits of the Korf Bay in Eastern Kamchatka, in *Ocherki po geologii severo-zapadnogo sektora Tikhookeanskogo tektonicheskogo poyasa* (Essays on Geology of the Northwestern Sector of the Pacific Tectonic Belt), Moscow: Nauka, 1987, pp. 5–73.

Gladenkov, Yu.B. and Shantser, A.E., Stratigraphy and Paleogeographic Grounds for Correlation of Geological Events of Neogene in the Kamchatka Region, in *Osadochnaya obolochka Zemli v prostranstve i vremeni: stratigrafiya i paleontologiya. 28 Mezhdunarodnyi geol. kongress. Doklady sov. geologov* (Sedimentary Cover of the Earth in Space and Time: Stratigraphy and Paleontology. 28th Int. Geol. Congr. Reports of Soviet Geologists), Moscow: Nauka, 1989, pp. 127–134.

Gladenkov, Yu.B. and Shantser, A.E., Geological Events in the Paleogene of Kamchatka, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 97–108.

Gladenkov, Yu.B., Sinel'nikova, V.N., Shantser, A.E., *et al.*, *Eotsen Zapadnoi Kamchatki* (Eocene of Western Kamchatka), Moscow: Nauka, 1991.

Grigorenko, Yu.N., Types and Associations of Clastic Rocks in the Paleogene Formations of Western Kamchatka, in *Kainozoi Dal'nego Vostoka SSSR* (The Cenozoic of the USSR Far East), Leningrad: Vses. Geol. Razved. Inst., 1981, pp. 63–91.

Grigor'ev, V.N. and Shapiro, M.N., Upper Cretaceous Volcanics of the Kamchatka Isthmus, *Tikhokean. Geol.*, 1986, no. 4, pp. 58–65.

Khubunaya, S.A., *Vysokoglinozemistaya plagiotoleitovaya formatsiya ostrovnykh dug* (High-Aliminum Plagiotholeiite Formation of Island Arcs), Moscow: Nauka, 1987.

Litvinov, A.F., Lopatin, V.B., Krikun, N.F., *et al.*, Stratigraphy of Paleocene–Neogene Deposits of the Ozernoi Peninsula (Eastern Kamchatka), *Tikhookean. Geol.*, 1990, no. 6, pp. 68–77.

Pozdeev, A.I. and Petrina, N.M., Age and Volume of the Kirganik Formation of Kamchatka, *Sov. Geol.*, 1984, no. 1, pp. 50–57.

Sadreev, A.M. and Dolmatov, B.K., New Data on the Volume and Age of Volcanic-Pyroclastic and Tuffaceous–Sedimentary Deposits of the Kronotskii Peninsula, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1965, no. 7, pp. 122–126.

Serova, M.Ya., *Foraminifery paleotsenovykh otlozhenii Vostochnoi Kamchatki* (Foraminifers in Paleocene Deposits of Eastern Kamchatka), Moscow: Nauka, 1966.

Shantser, A.E., Shapiro, M.N., Koloskov, A.V., *et al.*, Evolution of the Lesnaya Uplift Structure and Adjacent Areas in the Cenozoic (Northern Kamchatka), *Tikhookeanskaya Geol.*, 1985, no. 4, pp. 66–74.

Shapiro, M.N., Ermakov, V.A., Shantser, A.E., *et al.*, *Ocherki tektonicheskogo razvitiya Kamchatki* (Essays on Tectonic Evolution of Kamchatka), Moscow: Nauka, 1987.

Sinel'nikova, V.N., Skiba, L.A., Fot'yanova, L.I., *et al.*, *Rannii pliotsen Zapadnoi Kamchatki* (Early Pliocene of Western Kamchatka), Moscow: Nauka, 1979.

Tsukanov, N.V., *Tektonicheskoe razvitie priokeanicheskoi zony Kamchatki v pozdnem mezozoe–rannem kainozoe* (Tectonic Evolution of the Pacific Coast of Kamchatka in the Late Mesozoic–Early Cenozoic), Moscow: Nauka, 1991.

Valov, M.G., Chelebaeva, A.I., and Chigaeva, G.B., On a Hiatus Between Miocene and Pliocene Deposits in the Bystrtinskii Range of Central Kamchatka, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1978, no. 5, pp. 80–85.

Volobueva, V.N., Gladenkov, Yu.B., Ben'yamovskii, V.N., *et al.*, The Reference Section of the Marine Paleogene of the Northern Far East, *Tr. Sev.-Vost. Kompleksn. Nauch.-Issled. Inst. Dal'nevost. Otd. Ross. Akad. Nauk*, Magadan, 1994, vol. 1.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 580–593. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 61–74.
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New Data on the Geology of Iturup Island (Kuril Island Arc)

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Abstract—The geology of Iturup Island, which is the largest one in the Kuril island arc, has not yet been considered in any special publications. The island is marked by the occurrence of typical island-arc deposits of the middle Miocene–Pliocene age that show complicated facial variability. Based on the analysis of siliceous plankton assemblages (diatoms, radiolarians), the age of several formations distinguished in both the Iturup and Kunashir islands has been determined more accurately. Paleontologically dated levels of transgressive events correlative with similar levels in the Neogene section of the Karaginskii Island (eastern Kamchatka), the reference one in the Far East, have been defined.

Key words: *Kuril arc, Iturup, Kunashir, geological structure, diatoms, radiolarians.*

In 1992, scientists from the Geological Institute of the Russian Academy of Sciences conducted investigations of Iturup Island, the largest island in the Kuril island arc. It is part of the southern segment of the Greater Kuril Islands. The island extends to the northeast over a distance of about 200 km and is about 40 km wide in its central part (Figs. 1 and 2). There are 11 inactive and active volcanoes on the island whose lavas and pyroclastics cover large areas. Predominantly volcanogenic-sedimentary rocks underlying younger volcanites are exposed locally.

The largest outcrops of these rocks are observed in the central part of the island. Several boreholes were also drilled there; the deepest of them (Borehole 50) penetrated 1600 m of deposits. Such deep boreholes are important for the study of gently dipping deposits.

Field work was conducted in several areas: the Sea of Okhotsk coast near Kuril'sk and the Rybaki Settlement, the Saratovka River valley, Przheval'skii Cape, and along the Kuibyshevka River. In addition, cores from several boreholes were sampled to analyze diatom and radiolarian assemblages.

When sampling the sections, special attention was paid to their potential for the discovery of diatoms and radiolarians. Determination and age interpretation of diatoms were performed by T.V. Oreshkina and of radiolarians, by D.I. Vitukhin. The samples collected by Vitukhin in the southern Kuril islands in 1983 were also used for the analysis. These samples were collected in both Iturup and Kunashir islands. The comparison of data from these two islands is important because relationships of rock units in Iturup Island are interpreted by the researchers in different ways.

In total, about 300 samples, including 20 samples from cores of Borehole 20 drilled in the Kuril'sk area, were collected for the diatom and radiolarian analyses.

The early evolutionary stages of the Kuril island arc cannot be properly interpreted without answering the

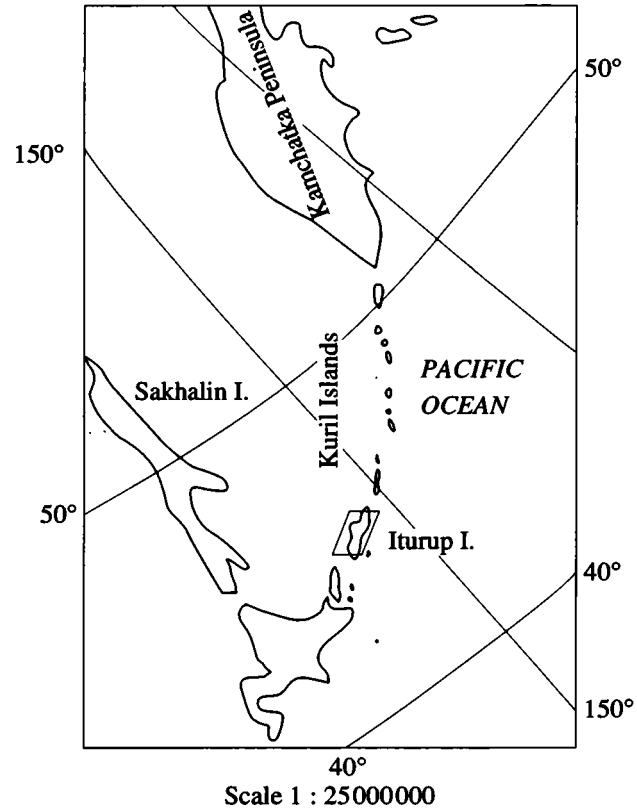

Fig. 1. Location of Iturup Island.

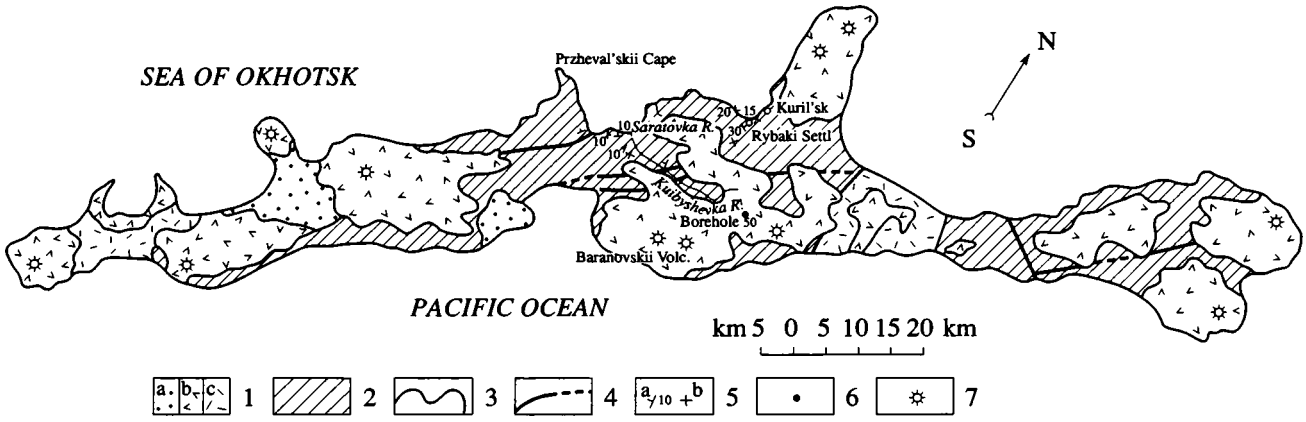

Fig. 2. Geological sketch map of Iturup Island (modified after *Geologicheskaya* ..., 1974). 1, Quaternary deposits: terrigenous (a) and volcanogenic: basic and intermediate (b) and acidic (c); 2, Miocene–Pliocene; 3, geological boundaries; 4, faults, undifferentiated; 5, occurrence: (a) vertical, (b) horizontal; 6, borehole location; 7, volcanoes, inactive and active.

following question: what is the oldest age of rocks composing the Greater Kuril Islands? This problem is emphasized by the fact that in the Komandor Islands of the adjacent Aleutian island arc (Shcherbinina, 1992) and in the Mariana island arc, the Eocene deposits were established, whereas in the Kuril Islands, rocks of this age are unknown so far. It should be admitted from the start that our efforts to discover coeval rocks in this area failed.

CHARACTERISTICS OF THE SECTION

At present, a universally accepted stratigraphic scheme of Cenozoic deposits in Iturup Island is not available because of their fragmentary distribution patterns, significant facial variability and poor paleontologic characteristics.

The first stratigraphic scheme for the Greater Kuril Islands was suggested by Japanese researchers. According to it, three formations were recognized in large islands: two of them (the Iriribushii and Rubetsu formations) were assigned to the Miocene and one (the Shana Formation), to the Pliocene (cited after Zhidkova *et al.*, 1971, p. 54). Since 1945, works in the island have been conducted by Soviet geologists.

Stratigraphic schemes published in several works dealing with geology of the Greater Kuril Islands differ from each other (Erokhov, 1960; Pryalukhina, 1961; Vergunov and Pryalukhina, 1963, 1965; Sergeeva, 1964; *Geologiya* ..., 1964; Davydov *et al.*, 1968; Bevz, 1975; Sergeev, 1976; Strel'tsov, 1976; Shmidt, 1987; *Geologo-geofizicheskii* ..., 1987; and others). Stratigraphy of Cenozoic deposits of the Kuril Islands was considered in greatest detail in several works (*Atlas* ..., 1972; *Biofatsial'nye* ..., 1975; Zhidkova *et al.*, 1971, 1972, 1975), in which, based on the analysis of previous materials, the following succession of stratigraphic units was suggested for Iturup Island (from the base upward):

(1) The basal strata of the sequence were referred to the Teben'kov Formation first distinguished by V.E. Bevz in 1964. Its type section is observed in the Kuibyshevka River middlestream at the western foot of the Mt. Teben'kov,[1] The formation deposits of about 1500 m in total thickness are mainly spread in the central part of the island and observed as isolated blocks in the Pacific coast. Lithologically, they are represented by pyroclastics and, less commonly, volcanogenic-sedimentary and effusive rocks of the basic and intermediate composition metamorphozed up to greenschist facies. The sequence is barren of organic remains. The early Miocene age of these deposits is arbitrarily determined based on their position in the sequence immediately below the lower-middle Miocene Kuibyshevka Formation whose age is paleontologically substantiated (*Atlas* ..., 1972).

It should be noted that the lowermost stratigraphic position in the island sequence was previously thought to be occupied by the Zhemchuzhnaya River Formation (Sergeeva, 1964), which resembles the Teben'kov Formation in lithology and rock alternation. The age of the former was believed to be the early Miocene. Later, however, the age of the Zhemchuzhnaya River Formation was revised to be assigned to the Pliocene (Bevz and Savitskii, 1972) and, thus, this unit ceased to be used.

(2) The lower-middle Miocene Kuibyshevka Formation was first distinguished by G.M. Vlasov in 1951. It unconformably rests upon underlying deposits and is 1200 m thick. The dominant rock varieties are tuffaceous diatomites, tuffstones, tuffites, and sandstones; tuffaceous gravelstones, small-pebbled conglomerates, tuffaceous agglomerates, and tuffaceous breccia occur in subordinate amount. The rocks of this formation are widespread in the central part of the island and along

[1] In publications, stratigraphic glossaries of the USSR (*Stratigraficheskii* ..., 1956, 1982), and geological reports, information on stratotypes of most formations is not available.

the coast of the Sea of Okhotsk. In the latter area, its typical sections are observed in the vicinity of Kuibyshevo Settlement and Maloe Lake and along the Kuibyshevka and Saratovka rivers. The age of the formation was inferred based on molluscan assemblages.

(3) The Rybaki Formation is assigned to the upper Miocene. It conformably overlies the Kuibyshevka Formation and is 700–1400 m thick. The formation was first defined by Yu.S. Zhelubovskii in 1951 along the Sea of Okhotsk coast between Kuril'sk and the Rybaki Settlement. It is also widely spread in the central part of the island. The type section of the formation was also described by Bevz in the Kuibyshevka River middle stream. The formation sequence is composed of tuffaceous breccia and conglomerates alternating with tuffaceous siltstones and diatomites, tuffstones, and gravelstones. The age of the formation was determined based on molluscan and diatom fossils.

(4) The 1000-m-thick Kamui Formation (upper Miocene–lower Pliocene) was first distinguished by Bevz in 1963 in the northern part of the island. Its type section is located in the Medvezh'ya River basin. The coeval deposits in the central part of the island (the Osennyaya and Blagodatnaya rivers) were named by Sergeeva (1964) as the Osennyaya River Formation. The Kamui Formation unconformably overlies the Rybaki Formation and is mostly composed of tuffaceous diatomites and siltstones with subordinate layers of tuffaceous conglomerates, tuffstones, and gravelstones. The age of the formation was determined based on molluscan remains.

(5) The Parusnoe Formation that occupies the uppermost position in the Cenozoic sequence was first defined by Vlasov in 1948 in the northwestern part of the island. The formation stratotype is located in the vicinity of Parusnoe Settlement (*Stratigraficheskii ...*, 1982). Based on molluscan fossils, its age was somewhat arbitrarily determined to be the middle–late Pliocene. The thickness is 1300 m. For the most part (70%), it consists of coarse-clastic rocks: tuffaceous breccia and conglomerates, lava breccia, and basaltic andesite lavas; sandstone, siltstone, and gravelstone interbeds occur in subordinate amount. The formation rests upon older rocks with unconformity.

Most geologists conducting the geological survey in the island followed to variable extent this stratigraphic scheme.

Another stratigraphic scheme of Cenozoic deposits was proposed by V.M. Dunichev in 1974. Based on comprehensive studies of siliceous planktonic fossils (diatoms) from sections in the central part of the island and thus obtained datings, this researcher suggested that the Cenozoic sequence be divided into two units: the Kamui Formation (upper Miocene–Pliocene) and Parusnoe Formation (Pliocene). The principal distinction between them is in the composition of their volcanic sequences: the former incorporates a large amount of acidic volcanites, whereas in the latter, basic rocks predominate. It was also noted that deposits of the Kamui Formation are spread along the riverbeds and, less commonly, in the river valley sides, while the Parusnoe Formation rocks compose watersheds.

In recent years, geologists from the Iturup Hydrogeological Expedition and Sakhalin Geological Committee conducted hydrogeological and geological surveys in the Iturup Island. When doing so, V.I. Pchelkin and P.Yu. Kovtunovich shared in many respects Dunichev's views on the number and relationship of the formations.

We studied sections in the Kuril'sk, Rybaki Settlement, Kuibyshevskii Bay, and Przheval'skii Cape areas in the Sea of Okhotsk coast and along the Saratovka and Kuibyshevka rivers as well as cores from boreholes. The results of these studies confirmed the conclusions on facial variability within the Cenozoic sequence and, accordingly, the limited number of formations. At the same time, the gentle dipping of strata, block tectonics, and fragmentary character of exposures make it difficult to compile the continuous succession and to define the spatial relationships between different units. Nevertheless, despite these negative factors, transitions between volcanogenic, tuffaceous, sedimentary, and epigenetically altered propylitized rocks can occasionally be observed immediately in outcrops. For instance, south of Mt. Verblyud in the Kuibyshevka River midstream, upstream of the Rubchik River inflow, the transition from altered rocks to volcanogenic–sedimentary deposits (the Teben'kov and Kuibyshevka formations corresponding to the basal part of the island sequence) is exposed. Tuffaceous–sedimentary deposits are represented here by alternation of tuffaceous siltstones, sandstones, and diatomites containing mollusk and brachiopod remains and plant detritus. Upstream, these rocks give way to coarse-clastic tuffaceous deposits represented by tuffaceous and lava breccia incorporating andesite and basaltic andesite flows with massive and, less commonly, large-block jointing. Tuffbreccia contains, along with effusive rocks, small (up to 10–12 cm across) clasts of siliceous rocks bearing indeterminable radiolarian skeletons replaced by chlorite. This rock member shows facies variability and lacks visible bedding. Further upstream, the amount of effusives and subvolcanic bodies increases. Thin beds of propylitized rocks also appear and become thicker and more abundant upsection. These are bluish-, or light- to greenish-gray rocks often intensely foliated. Propylitization and epigenetic alteration affected various rocks: tuffbreccia, tuffs, and effusives. The increase in the abudance of volcanic and subvolcanic rock varieties is accompanied by the increased amount of altered rocks. There are grounds to believe that the much higher share of effusives and subvolcanic bodies and the appearance of altered rocks in the section indicate the proximity to the ancient volcanic center.

Similar relationships of volcanogenic–sedimentary and propylitized rocks were observed in Boreholes 1K and 54 drilled in the Baranskii Volcano area (Fig. 3).

The relationships between different volcanogenic–sedimentary facies can be exemplified by sections outcropping in the coastal escarpment along the northwestern Kuibyshevka Bay. Here, the volcanogenic–sedimentary unit with low dip angles (10°–15°) is composed of large-block tuffaceous rocks replaced westward (along the strike) by the volcanogenic sequence incorporating abundant andesite lava flows with columnar and radiated jointing. Further northward along the coast, these rocks give way to coarse tuffbreccia with lenslike beds (up to 0.5–1.5 m thick) of thin-bedded tuffstones with pumice clasts. The apparent thickness of the unit is about 100 m.

The alternation patterns of volcanogenic–sedimentary rocks can be exemplified by the section exposed to the west of the Belavin Bay (from the base upward):

1. Andesite and basaltic andesite lavas with columnar jointing. The thickness is 5 m;

2. Tuffaceous conglomerates and breccia, massive, with blocks (up to 0.5–1.0 m across) of highly vesicular pyroxene-porphyritic andesites. The thickness is 20 m;

3. Alternation of tuffaceous sandstones, gravelstones, and small-pebbled conglomerates. The thickness is 25 m;

4. Tuffaceous breccia, poorly sorted, with distinct bedding. The thickness is 20–25 m.

Additional information can be obtained from borehole cores, which allow a continuous section for the central part of the Iturup Island to be assembled (see Fig. 3). In this area, a uniform rock association occurs. According to the lithification degree, it can be subdivided into two units: (1) a lower one composed of highly lithified volcanogenic and tuffaceous–sedimentary rocks, locally with intense hydrothermal alteration; and (2) an upper one consisting mostly of poorly lithified tuffaceous–sedimentary rocks. The base of this sequence is not exposed in the island. In boreholes, the basal portion of the lower unit (not less than 600 m thick) is composed of tuffaceous siltstones and fine-grained sandstones that are replaced upsection by coarse tuffaceous breccia, tuffs, often propylitized tuffacceous gravelstones, and thin interbeds of tuffaceous siltstones and tuffstones. Bodies of massive, less commonly large-block andesites are present. Higher in the section, light- to yellowish-gray, bleaching at the surface siltsones, tuffstones, and tuffaceous gravelstones and, less commonly diatomites, occur. Tuffaceous gravelstones incorporate beds of coarse-clastic tuffaceous breccia and isolated pebbles and clasts of effusive rocks of basic and intermediate composition. Sandstones contain molluscan remains. The upper part of the section is composed of coarse tuffaceous conglobreccia and large-block breccia with chaotic texture, bedded tuffstones, and tuffaceous conglomerates with unclear bedding. Volcanics of basic and intermediate composition predominate among clasts; acidic varieties also occur. Andesitic and basaltic lava flows are common through the sequence. The upper rock unit is composed of semilithified, often loose tuffaceous–sedimentary deposits represented by tuffaceous siltstones, tuffstones, and sands incorporating effusive blocks of intermediate and acidic composition.

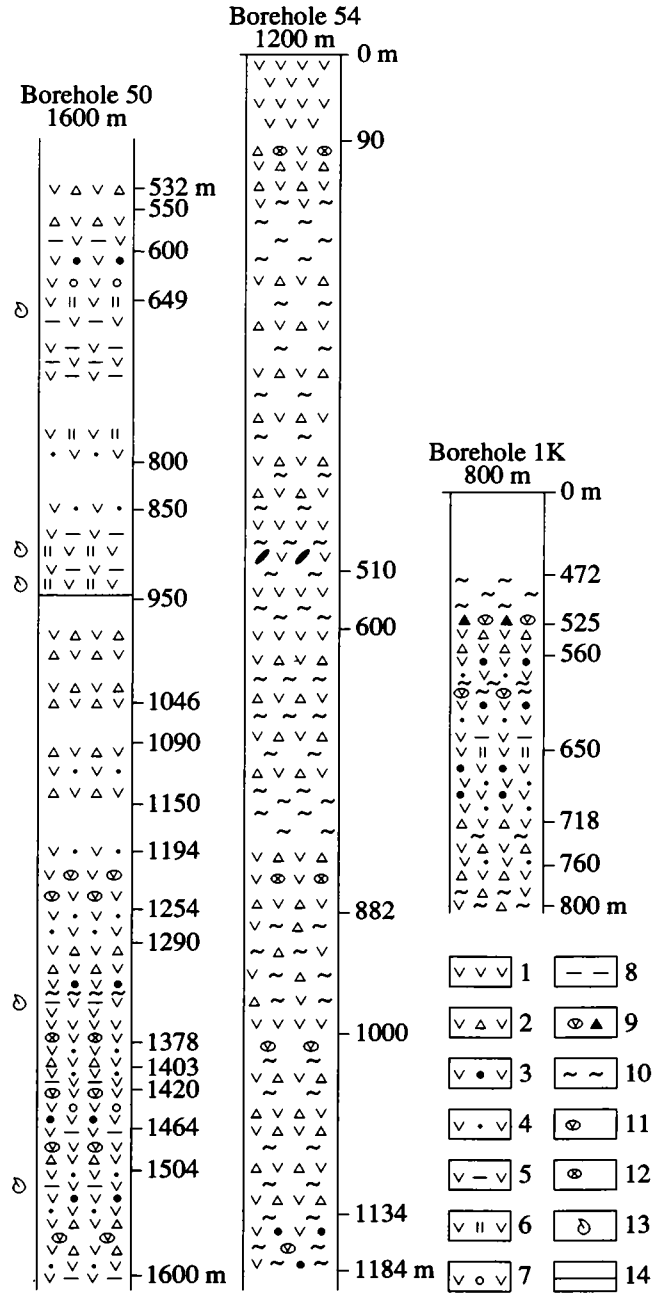

Fig. 3. Cenozoic sections in Iturup Island (based on borehole data). 1, effusive rocks; 2, tuffaceous breccia; 3, tuffaceous gravelstones; 4, tuffstones; 5, tuffaceous siltstones; 6, tuffaceous diatomites; 7, tuffaceous conglomerates; 8, siltstones; 9, lava breccia; 10, hydrothermally altered rocks; 11, 12, clasts of basic and intermediate (11) and acidic (12) rocks; 13, samples for micropaleontological analysis; 14, boundary between the lower and upper units.

MICROPALEONTOLOGIC CHARACTERISTICS OF DEPOSITS

In 1950–1960s, diatoms from the Kuibyshevka and Rybaki formations were studied by several researchers (Jouse, 1959, 1962; Kozyrenko and Sheshukova-Poretskaya, 1967). The marine diatom assemblage established there was referred to the late Miocene–Pliocene. According to recent views, it falls into the interval of 4.4 to 2.5 Ma. In the upper Rybaki Formation, this assemblage is replaced by the brackish-water lagoonal assemblage of Pliocene age. Debatable and requiring revision is the find of Paleogene species in the Kuibyshevka Formation (Vekshina, 1968), where they associate with the Pliocene diatom forms. In the 1970s, diatom flora was studied in sediments from the adjacent sea area, the Bussol' Strait separating the Chernye Brat'ya Islands from the Simushir Island (Greater Kurils), and in the outer shelf of the Lesser Kurils (Vasil'ev *et al.*, 1979; Vasil'ev and Suvorov, 1979). Marine diatom assemblages of the Oligocene–early Miocene, middle Miocene, mid-Pliocene, and late Pliocene age have been recorded in these localities. The mid-Pliocene assemblage appeared to be analogous to that from the Kuibyshevka and Rybaki formations.

As it was previously mentioned, Dunichev was the first to use widely the siliceous plankton for subdividing and dating the sedimentary deposits of Iturup Island (diatom determinations have been performed by V.P. Boldyrev). This brought completely new stratigraphic interpretations.

According to his preliminary report dealing with the geology of the central part of the island, the Kuibyshevka, Rybaki, and Kamui formations were interpreted to be age and facies analogues. They were assigned to the Miocene–Pliocene based on diatom evidence. In the Osennyaya River valley, where the stratotype of the Osennyaya River Formation is located, Dunichev established the analogues of the Kamui Formation, which was dated by diatoms as the late Miocene–Pliocene. It yielded the diatom assemblage with *Denticula* (=*Neodenticula*) *kamtschatica* similar to the diatom assemblage from the Maruyama Formation of southern Sakhalin. The recent, more detailed diatom zonation, in which the *Neodenticula kamtschatica* Zone is subdivided into three independent zones, provides the possibility to define the stratigraphic position of diatom assemblages more accurately (Fig. 4).

Additional information on siliceous plankton (diatoms, radiolarians) can be found in the paper by Runeva and Ushko (1984), who also studied deposits in the central part of the island. Based on diatom and radiolarian assemblages, these researchers have dated the Rybaki, Kamui, and Parusnoe formations as the late Miocene, early Pliocene, and middle–late Pliocene, respectively. Unfortunately, data on particular sections are absent in their paper.

Below, we discuss the results of our studies on Iturup Island stratigraphy.

The section comprising the Rybaki and, probably, uppermost Kuibyshevka formations was studied along the coast between Kuril'sk and the Rybaki Settlement.[2] The part of this section exposed 1.5 km northward of the Rybaki Settlement is composed of the following deposits (from the base upward):

1. Reddish-brown, massive gravelstones. The thickness is 1.5 m.

2. Bleached, bedded tuffaceous diatomites with intercalations of light-gray tuffstones. The thickness is 1 m.

3. Reddish-brown, massive gravelstones. The thickness is 8 m.

4. Alternation of brownish, compact tuffaceous siltstones and coarse-grained dark-brown tuffstones. The thickness is 1 m.

5. Massive, reddish-brown, coarse-grained tuffstones. The thickness is 1.5 m.

6. Greenish-brown, bedded, compact siltstones. The thickness is 1.5 m.

7. Yellowish-white tuffaceous diatomites. The thickness is 5 m.

8. Reddish-brown, massive, compact tuffstones. The apparent thickness is 10–15 m.

Further along the coast, one can observe only isolated outcrops of stratigraphically higher deposits represented by tuffaceous diatomites, siltstones, sandstones, and breccia.

Bed 2 yielded a diatom assemblage corresponding to the *Thalassiosira yabei* Zone (the uppermost middle–lowermost upper Miocene) of the diatom zonal scale (Fig. 4). The assemblage is typical of near-coast regions of the northwestern Pacific and consists of oceanic and neritic species. These are *Actinocyclus ingens* Rattr., *Thalassiosira yabei* (Kanaya) Akiba et Yanagisawa, *T. temperei* (Brun) Akiba et Yanagisawa, *T. grunowii* Akiba et Yanagisawa, *Azpeitia endoi* (Kanaya) Sims et Fryxell, *Pyxidicula schenckii* (Kanaya) Streln. et Nikolaev, *P. inermis* (Jouse) Streln. et Nikolaev, *Sheshukovia condecora* (Bright.) Gles., *Eucampia balaustium* Castr., *Xanthiopyxis diaphana* Forti, *Pterotheca subulata* Grun., *Ikebea tenuis* (Brun) Akiba, and *Stephanogonia hanzawae* Kanaya.

By radiolarians, this interval was referred to the *Lychnocanium nipponicum magnocornutum* Zone (uppermost middle–lower upper Miocene) of the Japanese radiolarian scale (Fig. 4; Table 1). The radiolarian assemblage is somewhat impoverished and consists, in addition to the zonal species, of *Lipmanella redondoensa* (Campbell et Clark), *Lichnocanium nipponi-*

[2] Taking into consideration that the number, volume, relationships, and spatial distribution of formations are differently treated in most publications and reports on geological structure of Iturup Island, we follow the scheme used in the geological map of the USSR, scale 1 : 200 000 (*Geologicheskaya* ..., 1974).

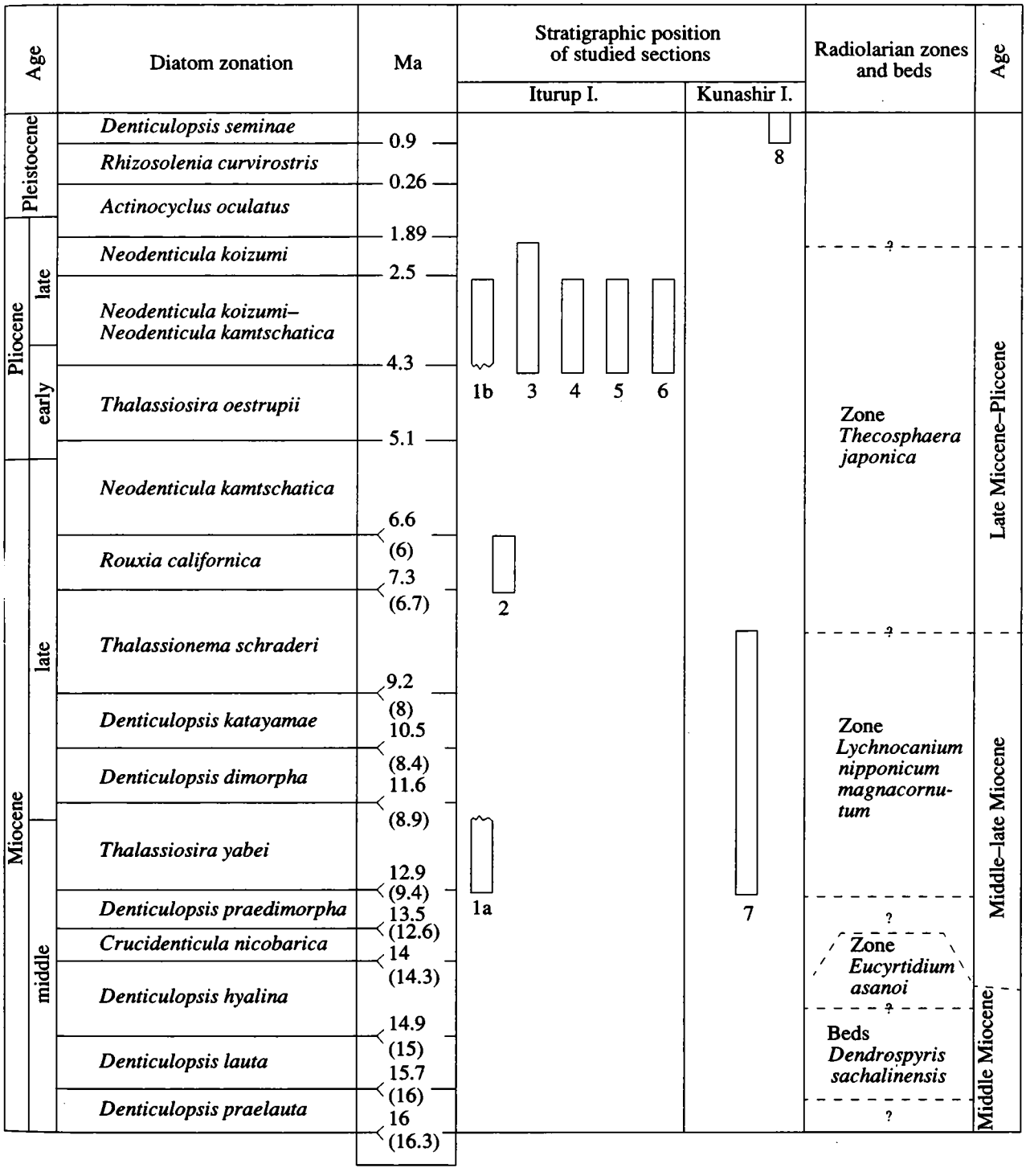

Fig. 4. Stratigraphic position of studied sections. Numbers in the figure denote the following sections: (1) between Kuril'sk and Rybaki Settlement; (1a) Kuibyshevka Formation, (1b) Rybaki Formation; (2) the road groove near Maloe Lake (Kuibyshevka Formation); (3) along the Kurilka River (Rybaki Formation); (4) the Kuibyshevka River downstream (Kuibyshevka Formation); (5) near the Pioner Settlement (Kuibyshevka Formation); (6) in the Saratovka River upper stream (Kuibyshevka and Kamui formations); (7) the Lovtsov Peninsula (Lovtsov Formation); (8) southern Kunashir Island (Alekhino Formation). Diatom zonation of the North Pacific is after Koizumi (1985), Akiba (1986), and Barron (1992). Boundary dating is after Barron (1992) and Koizumi (1985) by figures in and without brackets, respectively.

cum Nakaseko *magnocornatum* Funajama, *Spongodiscus osculosus* (Dreyer), and the *Lithocarpium polyacantha* (Campbell et Clark) group.

In Bed 7 and stratigraphically higher diatomites, a diatom assemblage corresponding to the *Neodenticula koizumi–Neodenticula kamtschatica* Zone (middle Pliocene) was determined. This assemblage is similar to the standard zonal assemblage of the considered zone despite the absence of *Neodenticula koizumi*, one of the zonal index species. The absence of the latter can be explained by the fact that its first appearance level occupies a progressively higher stratigraphic position when moving from higher toward lower latitudes and generally varies in age from 4.3 to 3.1 Ma. The assemblage is mainly marked by the appearance and permanent occurrence of species characteristic of the recent arctic-boreal latitudes (*Bacterosira fragilis* Gran and *Detonula confervaceae* (Cl.) Gran) and by replacement of the *Cosmiodiscus insignis* Jouse species by the *Cosmiodiscus intersectus* (Brun) Jouse form. The constant occurrence of oceanic species *Neodenticula kamtschatica* (Zabelina) Akiba et Yanagisawa and low abundance of benthic forms suggest sedimentation environments somewhat distant from the coast. Thus, the results of the diatom analysis revealed two transgressive levels: the middle Miocene (the *Thalassiosira yabei* Zone) and early Pliocene (the *Neodenticula koizumi–Neodenticula kamtschatica* Zone). The unit of regressive sediments about 10 m thick that separates these levels appeared to be barren of fossils; i.e., the middle Miocene and early Pliocene periods of biogenic silica accumulation are separated by a regressive cycle comprising the late Miocene and initial early Pliocene.

The rich radiolarian assemblage correlative to the *Thecosphaera japonica* Zone of the Japanese radiolarian scale (the upper most Miocene–Pliocene) was recorded in the upper part of the section (Bed 7). A similar assemblage was also found in the interval of 48–181.5 m of Borehole 20, whose description is given below, and in the Kurilka, Saratovka, and Kuibyshevka river valleys as well as in the Pioner Settlement area. However, in the four latter localities, the assemblage is notably impoverished. All the above-listed sections show the permanent presence of the following radiolarian species: *Thecosphaera japonica* Nakaseko, *Stylotrochus sol* Campbell et Clark, *Spongotrochus glacialis* Popofsky, the *Lithocarpium polyacantha* (Campbell et Clark) group, and *Lychnocanium* aff. *grande* Campbell et Clark. In the Borehole 20 section, radiolarians are more diverse. Their assemblage here is dominated by two species: *Thecosphaera japonica* Nakaseko and *Spongotrochus gracialis* Popofsky. Less common are *Artostrobus annulatus* (Bailey), *Siphocampe nodosaria* (Haeckel), *Stylodictya stellata* Bailey, and *Diplocyclas davisiana* Ehrenberg; single species of the suborder Spyridina also occur. In the section of the Kuril'sk and Rybaki Settlement area, this assemblage also includes *Stylosphaera angelina* Campbell et Clark, *Siphocampe sanpedpoana* (Campbell et Clark), and *Prunopyle titan* Campbell et Clark. The dominant species in the assemblage is *Siphocampe nodosaria* (Haeckel). The composition of the radiolarian assemblage suggests that host sediments were deposited in marine environments relatively far from the coast.

The diatom assemblage of the *Rouxia californica* Zone (the uppermost Miocene) was recorded in deposits outcropping approximately 1.5 km eastward of the Pioner Settlement in the road groove opposite the Maloe Lake. Here, a member of siliceous tuffaceous siltstone with an observable thickness of about 12 m is exposed. The base of the member is represented by the 0.7-m-thick bed of massive coarse-grained sandstone (the Kuibyshevka Formation). The diatom assemblage reveals a specific composition marked by the absence of pelagic diatom species of the *Denticulopsis* group that includes also the *Neodenticula* genus. This might have been explained by the general shallow-water aspect of the assemblage were it not for the wide development of another oceanic *Rhizosolenia* genus. The latter genus is represented here by *Rh. hebetata* var. *subacuta* Grunow (1884), the species first described from the bottom sediments in the Franz Josef Land area. Morphologically similar forms were also reported from Cenozoic deposits of different regions: *Rh. hebetata* f. *hiemalis* from Kamchatka (Sheshukova-Poretskaya, 1967, Plate 33, fig. 4); *Rhizosolenia* sp. 1 from Japan (Koizumi, 1968, Plate 34, fig. 26); and *Rhizosolenia* sp. 1 from the northeast Pacific (Schrader, 1973, Plate 9, fig. 18); Norwegian Sea (Schrader and Fenner, 1976, Plate 7, figs. 1 and 3), and eastern Antarctic (Harwood, 1976, Plate 3, fig. 7).

This species was also recorded in the northwestern Pacific near Kamchatka (DSDP Site 192), where its biozone was traced from the mid-upper Miocene to the Miocene–Pliocene boundary (the interval from Sample 192-24-2, 140–142 cm to Sample 192-18-5, 80–82 cm), i.e., within the scope of the *Thalassionema schraderi, Rouxia californica,* and *Neodenticula kamtschatica* zones. It should be noted that the decreased role of the *Denticulopsis* group in the *Rouxia californica* Zone is recorded elsewhere in the northwestern Pacific (Oreshkina, 1990). The composition of accompanying species is also characteristic of the upper half of the upper Miocene. These species are *Cavitatus jouseanus* (Sheshuk.) Williams, *Azpeitia endoi* (Kanaya) Sims et Fryxell, and *Pyxidicula zabelinae* (Jouse) Makar. et Moiss. s. str.

The assemblage of the *Neodenticula koizumi–Neodenticula kamtschatica* Zone was recorded in deposits outcropping along the Kurilka River (the Rybaki Formation), in the Kuibyshevka River lower stream, in the vicinity of the Pioner Settlement (the Kuibyshevka Formation), and in the Saratovka River upper stream (the Kuibyshevka and Kamui formations).

Similar diatom assemblage was also established in cores of Borehole 20 drilled in the Kuril'sk area. This

Table 1. Correlation of Neogene radiolarian zones and beds of the Russian Far East with radiolarian zonation of Japan

Correlation of zonal scale of Japan with oceanic zonation (Nakaseko and Sugano, 1973)				Radiolarian zones and beds of the Russian Far East	Correlation of zonal scale of Japan with zones established in DSDP Site 436 (Funajama, 1988)			
Age		Oceanic zonation (Riedel and Sanfilippo, 1970)	Zonal scale of Japan (Nakaseko and Sugano, 1973)		Zonal scale of Japan (Funajama, 1988)	Northwestern Pacific, DSDP Site 436 (Sakai, 1980)	Age	
Pliocene		*Pterocanium prismatium*	*Thecossphaera japonica*	Zone *Thecosphaera japonica*	Undefined	*Lamprocyrtis heteroporos*	late	Pliocene
		Spongaster pentas				*Sphaeropyle langii*	early	
Miocene	late	*Stichocorys peregrina*		?		*Stichocorys peregrina*	late	Miocene
		Ommatartus penultimus	*Lychnocanium nipponicum*	Zone *Lychnocanium nipponicum magnacornutum*		*Ommatartus penultimus*		
		Ommatartus antepenultimus			*Lycnocanoma nipponica magnacornuta*	*Ommatartus antepenultimus*		
	middle	*Cannartus* (?) *pettersoni*		?		*Cannartus pettersoni*	middle	
		Dorcadospyris alata	*Cyrtocapsella tetrapera*	Zone *Eucyrtidium asanoi*	*Eucyrtidium inflatum*	*Dorcadospyris alata*		
	early	*Calocycletta costata*	*Mellitosphaera magnaporulosa*	Beds with *Dendrospyris sachalinensis*	*Eucyrtidium asanoi*	Undefined		
					Calocycletta costata		early	

borehole penetrated the following units (from the top downward):

The interval of 0–48 m. Sands and sandstones with pebbles of effusive rocks;

The interval of 48–181.5 m. Mostly siltstones with sandstone interbeds;

The interval of 181.5–188.1 m. Sands with clasts of effusive rocks;

The interval of 188.1–188.7 m. Rock debris with clasts of effusive rocks;

The interval of 188.7–225 m. Light-gray andesites.

The interval of 48–181.5 m yielded the diatom assemblage of the *Neodenticula koizumi–Neodenticula kamtschatica* Zone (the mid-Pliocene). It is represented by two alternative ecological subassemblages, which evidently reflects both the change in the depth of sedimentation and the increase in the cold Kuril current influence. The first subassemblage suggesting simultaneously more oceanic and warmer conditions is characterized by the higher content of *Neodenticula kamtschatica* and mid-latitude species, and the second one, by the dominant role of neritic high-latitude species: *Pyxidicula zabelinae* (Jouse) Makar. et Moiss., *Thalassiosira gravida* Cl., *Detonula confervaceae* (Cl.) Gran, *Bacterosira fragilis* Gran, and *Odontella aurita* (Lyngb.) Agarth.

The assemblage of the *Neodenticula koizumi* Zone (upper Pliocene) was determined only from the section in the Kurilka River basin (the Rybaki Formation). It contains the zonal index-species *Neodenticula koizumi* Akiba et Yanagisawa, *Pyxidicula horridus* (Koizumi) Streln. et Nikolaev, and dominant *Rhizosolenia barboi* Brun. The assemblage is typical of the northwestern Pacific. The admixture of benthic diatom species against the background of general relatively oceanic composition of the assemblage can be related to turbidity activity.

Thus, at present, the oldest, reliably substantiated age of the Iturup Island deposits can be considered to be the terminal middle–initial late Miocene.

CORRELATION WITH THE KUNASHIR ISLAND

According to (*Atlas* ..., 1972), the following stratigraphic units are defined in the Kunashir Island:

1. The Kunashir Formation (lower Miocene?) 1500 m thick was first defined by Yu.S. Zhelubovskii and V.M. Chapyshev in 1951. It is most widespread in the northern part of the island (the Dokuchaev Range), in the Lovtsov Peninsula, and along the coast of the Sea of Okhotsk, where its most characteristic sections are exposed. The formation is composed of highly propylitized tuffs, tuffbreccia, basaltic andesite lavas and lava breccia, and less commonly includes hydrothermally altered volcanogenic–sedimentary rocks. It lacks any organic remains, which could clarify the age of deposits. Therefore, the age was arbitrarily determined based on its occurrence immediately below the Lovtsov Formation whose age is paleontologically substantiated.

2. The Lovtsov Formation (middle–upper Miocene) rests upon the erosion surface of the Kunashir Formation rocks. It is predominantly composed of tuffs with tuffaceous siltstone and tuffstone interbeds; at the base of the sequence, the thick (up to 150 m) conglomerate member occurs. The total thickness of the formation is 1500 m. It was first defined by the aforementioned researchers simultaneously with the previous formation. Its stratotype section was described along the oceanic coast of the Lovtsov Peninsula between the Spokoinyi Cape and Krugloe Lake (*Stratigraficheskii* ..., 1982). The age was determined based on molluscan remains.

Runeva and Ushko (1984) who studied the outcrops of the formation in the Lovtsov Peninsula confirmed its middle–late Miocene age. The radiolarian assemblage from these deposits corresponds, in Runeva's opinion, to the *Lychnocanium nipponicum* radiolarian zone (upper middle–lower upper Miocene).

Shmidt (1987) referred the Lovtsov Formation to the Paleogene. This researcher defined in its section three units (from the base upwards): (1) 300-m-thick volcanomictic breccias and tuffs; (2) 1000-m-thick fine-grained volcanogenic–biogenic rocks; and (3) 300-m-thick volcanomictic conglomerates interbedding with tuffstones and tuffaceous diatomites.

The Paleogene age was determined based on finds of two radiolarian species (determinations by Runeva) and nannofossils indeterminable at the species level (determinations by O.B. Dmitrenko).

However, from the sample collected 300 m higher from the formation base (i.e., from the base of the second unit, according the Shmidt's scheme), Vitukhin (1989) determined that the radiolarian assemblage with the *Lipmanella redondoensa* (Campbell et Clark) and *Lychnocanium nipponicum* Nakaseko *magnacornutum* (Funajama) corresponds to the *Lychnocanium nipponicum*

Plate I.

Diatoms representing Neogene stratigraphic markers of the Kuril Islands. Magnification of all figures is ×1000 except Figs. 15 and 16 (×1500). 1–4, 7–9, *Rhizosolenia hebetata* var. *subacuta* Grunow: 1 and 2, Sample 192-24-2, 140–142 cm, Site 192, DSDP Leg 19; 3, 4, 7–9, Sample 69, Iturup Island; 5, 6, *Cavitatus jouseanus* (Sheshuk.) Williams, Sample 69, Iturup Island; 10, *Rhizosolenia barboi* Brun, Sample 69, *ibid.*; 11, *Thalassiosira sancettae* Akiba, Sample 48, *ibid.*; 12, *Eucampia balaustium* Castracane, Sample 40, *ibid.*; 13, *Pyxidicula horridus* Koizumi, Sample, 48, *ibid.*; 14, *Actinocyclus ingens* Rattray, Sample 40, *ibid.*; 15, *Neodenticula koizumi* Akiba et Yanagisawa, Sample 48, *ibid.*; 16, *Neodenticula kamtschatica* (Zabelina) Akiba et Yanagisawa, Sample 36, Kunashir Island; 17, *Thalassiosira yabei* (Kanaya) Akiba et Yanagisawa, Sample 40, Iturup Island; 18, *Cosmiodiscus insignis* (Brun) Jouse, Sample 40, *ibid.*; 19, *Thalassiosira antiqua* (Grunow) Cleve, Sample 45, *ibid.*; 20, *Distephanus octangulatus* Wailes, Sample 9, Kunashir Island; 21, *Pyxidicula* aff. *"Coscinodiscus" pustulatus* Mann, Sample 48, Iturup Island.

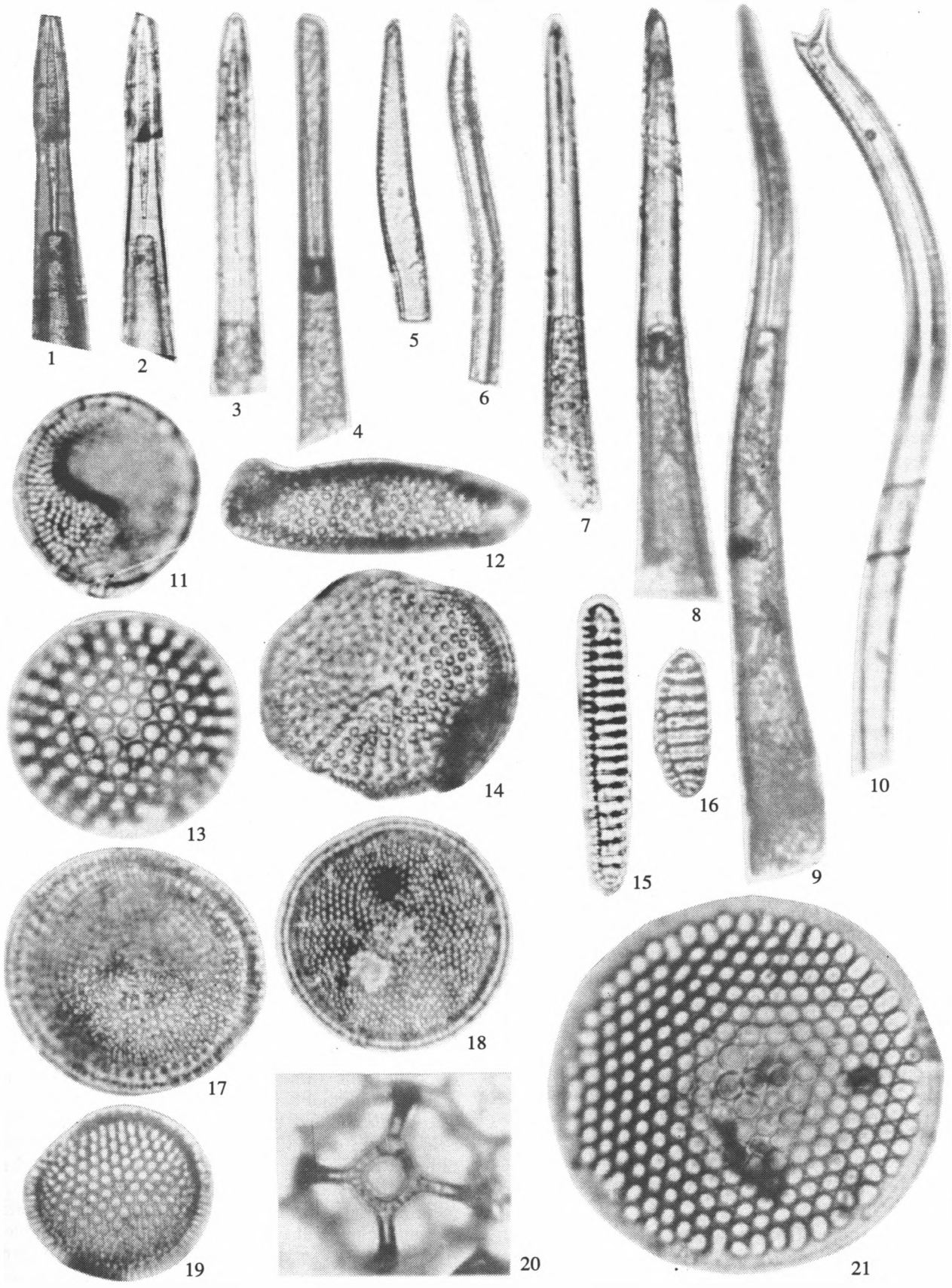
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Table 2. Correlation of Neogene stratigraphic units in Iturup Island

Age		Sasa, Nemoto (1959–1960)	*Geologiya ...*, 1964	Sergeeva, 1964	Zhidkova *et al.*, 1971*	Bevz, 1975	Present work	Age	
		Formation							
Pliocene	late	Shana	Parusnoe	Parusnoe	Parusnoe	Parusnoe	Parusnoe	late	Pliocene
	middle						— — —?— — —		
	early		Rybaki	Osennyaya River	Kamui	Kamui	Rybaki	early	
							— — —?— — —		
Miocene	late	Rubetsu		Rybaki	Rybaki	Rybaki	Kuibyshevka	late	Miocene
	middle		Kuibyshevka	Kuibyshevka	Kuibyshevka	Kuibyshevka	— — —?— — —	middle	
	early	Iriribushi	Zhemchuzhnaya	Zhemchuzhnaya River	Teben'kov	Teben'kov		early	

* Similar stratigraphic scheme was given in (*Atlas ...*, 1972; *Biofatsial'nye ...*, 1974).

magnacornutum Zone (upper middle–lower upper Miocene). A similar radiolarian assemblage was also recorded in rocks from the upper part of the formation outcropping at the Krugloe Lake coast. The rocks, from which radiolarians were extracted, are compact, almost porcelanitic. To extract radiolarian skeletons, hydrofluoric acid (HF) was used; however, this impeded the extraction of determinable diatom valves abundant in rocks. Therefore, the middle–late Miocene age of deposits was determined by radiolarians only.

3. The Alekhino Formation (upper Miocene–lower Pliocene) was first distinguished by V.M. Chapyshev in 1951. It unconformably overlies the older deposits and consists of volcanogenic–sedimentary rocks. The lower part of the formation is dominated by tuffaceous conglomerates, tuffaceous and lava breccias with tuffstone and tuffaceous diatomite interbeds. Its upper part is mostly composed of tuffaceous gravelstones, tuffstones, tuffites, and tuffaceous diatomites. The total thickness of the formation is 1400 m. Its distribution areas are located along both the Sea of Okhotsk and Pacific coasts. The stratotype of the formation is between the Lobanov and Alekhin creeks near the Sea of Okhotsk coast (*Stratigraficheskii ...*, 1982). The age was determined by molluscan remains. Runeva (Runeva and Ushko, 1984) and Boldyrev, who studied radiolarians and diatoms respectively, assigned the formation to the upper Miocene–Pliocene.

4. The Golovnino Formation (middle–upper Pliocene) was defined by B.N. Piskunov, T.P. Koroleva, and others from 1962 to 1965 in the southern part of the island. It is predominantly composed of marine and, to a lesser extent, lagoonal–continental, volcanogenic–sedimentary deposits with a total thickness of 450 m. The formation rests upon the erosional surface at the top of the Alekhino Formation. The age was determined by molluscan assemblages.

From the upper Golovnino Formation in the southern part of the island (in the Mechnikov and Puzanov capes area), Oreshkina determined the young diatom assemblage corresponding to the terminal Pleistocene–Holocene. This age estimate was confirmed by the presence of the recent silicoflagellate species *Distephanus octangulatus* Wailes, whose first occurrence level is dated as the terminal Pleistocene. The diatom assemblage consists of *Neodenticula seminae* (Simonsen et Kanaya) Akiba et Yanagisawa, *Odontella aurita* (Lyngb.) Agarth, *Porosira glacialis* (Grun.) Jorg., *Thalassiosira gravida* Cleve, *T. sancettae* Akiba, *Actinocyclus ehrenbergii* Ralfs, *A. curvatulus* Janisch, *Bacterosira fragilis* Gran, and *Navicula glacialis* Cl. The ecological structure of the assemblage is characteristic of shelf environments.

Thus, like in Iturup, deposits with organic remains of older than the middle Miocene fossils were not observed in Kunashir Island.

The analysis of available information and our data on the siliceous plankton revealed that existing stratigraphic schemes need to be revised. However, based on the results of investigations in only its central part, none of the available schemes for subdivision of the Cenozoic sequence into formations can unambiguously be accepted without additional detailed geological mapping in Iturup Island (from where most of our data were collected). For instance, no paleontologic data on the age of the Teben'kov Formation commonly correlated with the base of the sequence are available so far. Taking into consideration the fact that in its composition and rock alteration degree it is almost identical with the Zhemchuzhnaya River Formation (previously placed at the base of the sequence and later assigned to the Pliocene), the validity of the Teben'kov Formation is highly problematic. The oldest age estimates—middle (the *Thalassiosira yabei* Zone) and late (the *Rouxia californica* Zone) Miocene—were obtained for several samples collected only from deposits that are referred to the Kuibyshevka Formation (Fig. 1). Therefore, we recommend including this formation in the stratigraphic scheme at the base of the sequence (Table 2). According to our data, the Pliocene (mainly upper Pliocene) rocks, which are spatially distributed mostly in the central part of the island (leaving aside Quaternary

deposits), could be united into the Rybaki Formation keeping in mind the place where it was first distinguished (the Rybaki Settlement; here, we determined its Pliocene age) and its undebatable position above the Kuibyshevka Formation.

We have not studied the type sections of the Kamui Formation. As for the Parusnoe Formation, we failed to extract siliceous fossils from its rocks.[3]

In general, the methodical approach to the stratigraphic subdivision of the Cenozoic deposits of the Kuril Islands and, probably, of other island arcs, needs to be revised. In the areas characterized by the variable facies composition and fast lateral changes from shallow-water shelf deposits to relatively deeper, outer shelf-bathyal (1–2 km deep) sediments with abudant coarse-grained rocks, it is probably reasonable to distinguish stratigraphic units, which would correspond to the transgressive–regressive cycles reflecting the sum effect of regional tectonics and eustatic sea-level fluctuations.

We defined and dated several transgressive levels. The first of them was referred to the terminal middle Miocene (the *Thalassiosira yabei* Zone). The second one falls into the late Miocene (the *Rouxia californica* Zone). The third cycle correlates with the mid-Pliocene or, to be more precise, with the *Neodenticula koizumi–Neodenticula kamtschatica* Zone. It was recorded in most studied localities and is characterized by relatively deeper-water diatom, silicoflagellate, and radiolarian assemblages. The fourth and fifth cycles are confined to the terminal Pliocene (the *Neodenticula koizumi* Zone) and terminal Pleistocene–Holocene, respectively. Thus, nearly all the transgressive levels, except the early Miocene one (the *Crucidenticula kanayae* Zone), which were earlier established in the reference section of the Karaginskii Island (eastern Kamchatka) (Basilyan *et al.*, 1993), were recognized in the Neogene sequence of Iturup Island.

CONCLUSION

Thus, the investigation conducted in Iturup and Kunashir islands revealed that typical island-arc deposits represented by volcanogenic–sedimentary, volcanogenic, and sedimentary rocks are typical of them. In age, they range from the middle Miocene to Pliocene. The sequence, whose total thickness makes up thousands of meters, is featured by complex facies variability. The rocks composing the sequence have been formed in the environments of the volcanic archipelago with highly differentiated relief: coarse volcanogenic rocks accumulated near the volcanic centers, and fine-grained and better sorted deposits, at their periphery. During periods when volcanic activity stopped fine tuffaceous–sedimentary deposits were formed. This rock association is overlain by recent volcanics. The altered rocks termed "green tuffs" are widespread. The origin of these rocks should be accounted for either recent or earlier hydrothermal and volcanic activity. The hydrothermal fluid migration was favored by faults.

The sections studied here show slight deformations. Like in other Kuril Islands, subvertical faults appear to be the main type of deformations. Folds are not characteristic. Dip angles vary in the range of 10°–30° and are the highest in the fault zones. Volcanics reveal intermediate and acidic composition (Piskunov, 1975), which accords well with the significant crust thickness up to 30 km (Vr = 7.5–7.8 km/s) in the Iturup area (Ermakov *et al.*, 1989). This fact allows us to suggest that this structure can be ascribed to the arcs of the ensimatic type. The granite–metamorphic layer is characterized here by the mature state favorable for the high degree of the autochtonous accretionary process.

[3] Samples for radiolarian and diatom analyses from the Parusnoe Formation were collected in 1986 in the Przheval'skii Cape area by A.E. Basilyan, a scientist from the Geological Institute of the Russian Academy of Sciences.

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REFERENCES

Akiba, F., Middle Miocene to Quaternary Diatom Biostratigraphy in the Nankai Trough and Japan Trench and Modified Lower Miocene through Quaternary Diatom Zones for Middle to High Latitudes of the North Pacific, in *Initial Rep. Deep Sea Drill. Proj*, Washington: US Gov. Print. Off., 1986, vol. 87, pp. 393–480.

Atlas neogenovykh mollyuskov Kuril'skikh ostrovov (Atlas of Neogene Mollusks from the Kuril Islands), Moscow: Nauka, 1972.

Barron, J.A., Neogene Diatom Datum Levels in the Equatorial and North Pacific, *The Centenary of Japanese Micropaleontology*, Saito, T. and Ishizaki, K., Eds., Tokyo: Terra Sci., 1992, pp. 413–425.

Basilyan, A.E., Vitukhin, D.I., and Oreshkina, T.V., Upper Cenozoic of Eastern Kamchatka, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1993, vol. 68, no. 5, pp. 79–94.

Bevz, V.E., The Standard Stratigraphic Scheme of Neogene Deposits of the Kuril Islands and Their Formational Subdivision, in *Geologiya, poleznye iskopaemye, metodika i tekhnika geologorazvedochnykh rabot na Sakhaline i Kuril'skikh ostrovakh* (Geology, Mineral Resources, and Methodology of Geological-prospecting Works in Sakhalin and Kuril Islands), Yuzhno-Sakhalinsk: Sakhalin Otdel. Dal'nevost. Knizhn. Izdat., 1975, pp. 58–61.

Bevz, V.E. and Savitskii, V.O., Stratigraphic Position of the Zhemchuzhnaya River Formation in the Neogene Section

of Iturup Island (South Kuril Islands), *Izv. Geogr. O-va SSSR*, 1972, no. 3, pp. 101–105.

Biofatsial'nye osobennosti mezokainozoiskikh basseinov Sakhalina i Kuril'skikh ostrovov (Biofacial Peculiarities of Mesozoic–Cenozoic Basins of Sakhalin and Kuril Islands), Novosibirsk: Nauka, 1974.

Davydov, M.N., Dunichev, V.M., and Taboyakov, A.D., New Data on Neogene Deposits of the Southern Greater Kurils (Urup, Iturup, Kunashir), *Geol. Geofiz.*, 1968, no. 12, pp. 112–116.

Ermakov, V.A., Levynin, A.I., and Zlobin, T.N., Composition and Structure of the Earth Crust and Mantle of the Kuril Islands, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1989, no. 10, pp. 18–37.

Erokhov, V.F., New Data on Age of Neogene Deposits of the Northeastern Iturup Island (Kuril Islands), *Dokl. Akad. Nauk SSSR*, 1960, vol. 130, no. 2, pp. 385–386.

Funajama, M., Miocene Radiolarian Stratigraphy of the Suzn Area, Northeastern Part of the Noto Peninsula, *Contrib. Japan. Inst. Geol. Paleontol.*, 1988, no. 91, pp. 15–41.

Geologicheskaya karta SSSR, ser. Kuril'skaya, Masshtab 1 : 200 000 (Geological Map of the USSR, Kuril Ser., Scale 1 : 200 000), Compiled by Bevz, V.E. and Shaposhnikov, A.V., Moscow: Aerogeologiya, 1974.

Geologiya SSSR, t. 31: Kamchatka, Kuril'skie i Komandorskie ostrova, chast' 1 (Geology of the USSR, Vol. 31, Kamchatka, Kuril, and Komandor Islands, Part. 1), Moscow: Nedra, 1964.

Geologo-geofizicheskii atlas Kuril'sko-Kamchatskoi ostrovnoi sistemy (Geological-Geophysical Atlas of the Kuril-Kamchatka Island System), Krasnyi, M.L., Ed., Leningrad: Vsesoyuz. Geol. Inst., 1987.

Grunow, A., Die Diatomeen von Franz Josef Land, *Denkschr. Kgl. Akad, Wiss. Wien, Math.-Naturwiss., Cl.*, 1884, vol. 48, no. 2, pp. 53–112.

Harwood, D.M., Diatom Antarctic Cenozoic History from MSSTS-1 Drillhole, McMurdo Sound, *Wellington DSIR Bull.*, 1986, vol. 237, pp. 69–107.

Jouse, A.P., Main Stages in Evolution of Flora of Marine Diatom Algae (Diatomea) in the Far East, the Tertiary Through Quaternary, *Bot. Zh.*, 1959, vol. 44, no. 1, pp. 44–55.

Jouse, A.P., *Stratigraficheskie i paleogeograficheskie issledovaniya v severo-zapadnoi chasti Tikhogo okeana* (Stratigraphic and Paleogeographic Investigations in the Northwestern Pacific), Moscow: Akad. Nauk SSSR, 1962.

Koizumi, I., Diatom Biochronology for Late Cenozoic Northwest Pacific, *J. Geol. Soc. Jpn.*, 1985, vol. 91, no. 3, pp. 195–211.

Koizumi, I., Tertiary Diatom Flora of Oga Peninsula, Akita Prefecture, Northeast Japan, *Sci. Rep. Tohoku Univ., Ser. 2*, 1968, no. 3, pp. 171–240.

Kozyrenko, T.F. and Sheshukova-Poretskaya, V.S., Materials on Studies of Neogene Diatoms of the Southern Kuril Islands, *Vestn. Leningr. Univ., Ser. Biol.*, 1967, no. 4, issue 21, pp. 38–104.

Nakaseko, K. and Sugano, K., Neogene Radiolarian Zonation In Japan, *Osaka Univ. Sci. Rep.*, 1973, vol. 8, pp. 23–33.

Oreshkina, T.V., Neogene Diatoms from the Northwestern Pacific (Stratigraphy and Paleocaenography), *Cand. Sci. (Geol.–Mineral.) Dissertation*, Moscow: Geol. Inst. Acad. Sci. USSR, 1990.

Piskunov, B.N., *Vulkanizm Bol'shoi Kuril'skoi gryady i petrologiya vysokoglinozemistoi serii* (Volcanism in the Greater Kurils and Petrology of the High-Al Series), Novosibirsk: Nauka, 1975.

Pryalukhina, A.F., Materials on Stratigraphy of the Southern Kuril Islands, *Tr. Sakhalin. Nauchno-Issled. Inst., Geol. Geofiz.*, 1961, no. 10, pp. 3–13.

Riedel, W.R. and Sanfilippo, A., Radiolaria, Leg 4, Deep Sea Drilling Project, in *Initial Rep. Deep Sea Drill. Proj.*, Washington: US Gov. Print. Off., 1970, vol. 4, pp. 503–575.

Runeva, N.P. and Ushko, K.A., Neogene Radiolarians of the Greater Kurils and Their Stratigraphic Significance, in *Mikrofauna neftegazonosnykh raionov SSSR* (Microfauna of the Oil- and Gas-bearing Areas of the USSR), Leningrad: Vsesoyuz. Nauchn.-Issled. Geol.-Razved. Inst., 1984, pp. 94–101.

Sakai, T., Radiolarians from Sites 434, 435, and 436, Northwest Pacific, Leg 56, Deep Sea Drilling Project, in *Initial Rep. Deep Sea Drill. Proj.*, Washington: US Gov. Print. Off., 1980, vol. 56/57, pp. 695–733.

Sasa, Y. and Nemoto, T., Geologic Map of Nemuro, Hokkaido, Chishima, Scale 1 : 250 000, 12 Sheets, Tokyo: Geol. Surv. Japan, 1959–1960.

Schrader, H.J., Cenozoic Diatoms from the Northeast Pacific, Leg 18, in *Initial Rep. Deep Sea Drill. Proj.*, Washington: US Gov. Print. Office, 1973, vol. 18, pp. 673–797.

Schrader, H.J. and Fenner, J., Norwegian Sea Cenozoic Diatom Bistratigraphy and Taxonomy, in *Initial Rep. Deep Sea Drill. Proj.*, Washington: US Gov. Print. Office, 1976, vol. 38, pp. 605–671.

Sergeev, K.F., *Tektonika Kuril'skoi ostrovnoi sistemy* (Tectonics of the Kuril Island Arc), Moscow: Nauka, 1976.

Sergeeva, B.O., On Stratigraphy of Neogene Deposits of Iturup Island (Kuril Islands), *Dokl. Akad. Nauk SSSR*, 1964, vol. 156, no. 4, pp. 834–837.

Shcherbinina, E.A., Stratigraphy and Paleooceanography of the Pacific Based on Nannoplankton, *Cand. Sci. (Geol.–Mineral.) Dissertation*, Moscow: Geol. Inst. Acad. Sci. USSR, 1992.

Sheshukova-Poretskaya, V.S., *Neogenovye morskie diatomovye vodorosli Sakhalina i Kamchatki* (Neogene Marine Diatom Algae of Sakhalin and Kamchatka), Leningrad: Leningrad. Gos. Univ., 1967.

Shmidt, O.A., On Tectonics of the Kunashir Island (Kuril Islands), in *Ocherki po geologii Severo-Zapadnogo sektora Tikhookeanskogo podvizhnogo poyasa* (Essays on Geology of the Northwest Pacific Mobile Belt), Moscow: Nauka, 1987, pp. 226–238.

Stratigraficheskii slovar' SSSR (Stratigraphic Glossary of the USSR), Moscow: Gosgeoltekhizdat, 1956.

Stratigraficheskii slovar' SSSR: paleogen, neogen, chetvertichnaya sistema (Stratigraphic Dictionary of the USSR: Paleogene, Neogene, Quaternary), Leningrad: Nedra, 1982.

Strel'tsov, M.N., *Dislokatsii yuzhnoi chasti Kuril'skoi ostrovnoi dugi* (Deformations in the Southern Kuril Island Arc), Moscow: Nauka, 1976.

Vasil'ev, B.I. and Suvorov, A.A., Geological Structure of the Bussol' Seamount Area (Kuril Island Arc), in *Novye dannye po geologii dal'nevostochnykh morei* (New Data on Geology of the Far East Seas), Vladivostok: Tikhookean. Okeanol. Inst. Dal'nevost. Nauchn. Tsentr. Akad. Nauk SSSR, 1979, pp. 58–68.

Vasil'ev, B.I., Kornilova, R.M., and Boldyreva, V.P., Neogene Deposits of the Outer Zone of the Lesser Kurils, in *Novye dannye po geologii dal'nevostochnykh morei* (New Data on Geology of the Far East Seas), Vladivostok: Tikhookean. Okeanol. Inst. Dal'nevost. Nauchn. Tsentr. Akad. Nauk SSSR, 1979, pp. 40–57.

Vekshina, V.N., Middle Miocene Diatom Assemblage of the Kuril Islands, in *Iskopaemye diatomovye vodorosli SSSR* (Fossil Diatom Algae of the USSR), Moscow: Nauka, 1968, pp. 37–41.

Vergunov, G.P. and Pryalukhina, A.F., Pliocene Deposits of the Kuril Islands, *Dokl. Akad. Nauk SSSR*, 1963, vol. 152, no. 6, pp. 1420–1424.

Vergunov, G.P. and Pryalukhina, A.F., Miocene Deposits of the Kuril Islands, *Dokl. Akad. Nauk SSSR*, 1965, vol. 164, no. 6, pp. 1359–1363.

Vitukhin, D.I., Neogene Radiolarian Assemblages of the Kuril Islands (Kunashir, Iturup), in *Kainozoi Dal'nego Vostoka* (Cenozoic of the Far East), Vladivostok: Biol.-Pochven. Inst. Dal'nevost. Otdel. Akad. Nauk SSSR, 1989, pp. 206–208.

Zhidkova, L.S., Bevz, V.E., Neverova, T.I., and Sheremet'eva, G.N., Neogene Biostratigraphy of the Greater Kurils. Part I. Severo-Kuril'skii Horizon, *Izv. Sakhalin. Otd. Geogr. O-va SSSR*, 1971, no. 2, pp. 53–68.

Zhidkova, L.S., Bevz, V.E., Neverova, T.I., and Sheremet'eva, G.N., Neogene Biostratigraphy of the Greater Kurils. Part II. Srednekuril'skii Horizon, *Izv. Sakhalin. Otdel. Geogr. O-va SSSR*, 1972, no. 3, pp. 86–101.

Zhidkova, L.S., Bevz, V.E., and Sheremet'eva, G.N., Neogene Biostratigraphy of the Greater Kurils. Part III. Vostochnokuril'skii and Yuzhnokuril'skii Horizons, *Tr. Sakhalin. Kompleks. Nauchno-Issled. Inst. Dal'nevost. Nauchn. Tsentr Akad. Nauk. SSSR*, 1975, no. 36, pp. 5–13.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 594–605. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 75–87.
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Stratigraphic Scheme of the Quaternary (Anthropogene) Deposits in Belarus

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Abstract—A new stratigraphic scheme of the Quaternary deposits of Belarus is discussed. The scheme is based on the principle of succession in evolution of the fossil biota during the interglacial Pleistocene epochs. Stages in the evolution of natural complexes are identified by assuming only one optimum in the interglacial beds. It is suggested to subdivide the Quaternary System of Belarus into the Eopleistocene, Mezopleistocene, Neopleistocene and Holocene, and to accept the lower boundary age of the Pleistocene as corresponding to 1.65 Ma. The Eopleistocene is subdivided into five regional horizons, the constituent units of two superhorizons. Mezopleistocene includes eight regional horizons, among which three lower units represent the Minsk Superhorizon. The lower Neopleistocene boundary was transposed down to the base of the Dnieper Horizon because boundaries between Pleistocene units drawn at the base of glacial horizons are more logical and convenient.

Keywords: *stratigraphy, Pleistocene, horizon, glaciation, interglaciation, Belarus, flora, fauna.*

Thick Pleistocene deposits, whose topography and buried relief display traces of accumulative and erosional activity of continental glaciers together with glaciodynamic structures formed by them, and also the presence of interglacial, interstadial, and periglacial beds containing diverse and well-studied biota denote that the territory of Belarus is one of the main stratigraphic regions of the ancient glaciation in the East European platform. The problem of a detailed subdivision of the Pleistocene sequence in Belarus and adjacent territories was especially evident in recent years. This is connected with both the large-scale geological survey of the country, which is mainly aimed at the prediction and prospecting of mineral resources, and the extremely aggravated ecological situation influencing not only the subsurface, but also underlying sediments. At present, there is no reliable stratigraphic scale corresponding to available data on the structure of the Pleistocene sequence in Belarus. Field geologists use the stratigraphic scale approved in 1982 by the Interdepartmental Stratigraphic Commission of the USSR. This scheme does not meet the present-day requirements, because it simplifies the structure of the lower and middle Pleistocene. In contrast, Voznyachuk's stratigraphic scheme (1985) is extremely complicated, and many of its details are insufficiently substantiated. Stratigraphic schemes of other authors (Makhnach *et al.*, 1970; Goretskii, 1970; Makhnach, 1971; Gurskii *et al.*, 1986) also have shortcomings, and restrict the Pleistocene by boundaries of the Brunhes paleomagnetic epoch (0.73 Ma).

Researchers from the Laboratory of Anthropogene Geology of the Institute of Geosciences, Belarussian Academy of Sciences, suggested a new stratigraphic scheme of the Quaternary deposits of Belarus. Its principles were discussed previously (Velichkevich, 1990; Velichkevich *et al.*, 1992, 1993). The scheme is based upon complex biostratigraphic substantiation of the age of fossil floras and faunas, and also upon data on the evolution of the most characteristic groups of Pleistocene plants and animals. For the territory of Belarus, we used all available data on palynology, paleocarpology, diatom analysis, paleoentomology, and on the study on mollusks and small mammals. We studied the reference stratigraphic sections, key areas, and stratotypical regions. Our investigations were controlled by geological, geomorphological, and paleopotamological data, and, if necessary, by paleoclimatic, paleoecological, geochronological, and other materials.

When reconstructing stages in the evolution of natural Pleistocene complexes of Belarus, we assumed the interglacial periods to include only one optimum, i.e. consisting of the beginning of interglaciation, its climatic optimum and postoptimal phase, all definitely limited in time. The so-called "secondary," "small," additional optima typical of the Pleistocene sequence are considered as supplementary, accompanying the main optimum. In fact, they are either artificial optima resulting from the redeposition of interglacial fossils, or represent interstadials of different rank associated with one or another glacial epoch. In understanding the evolution of glaciations, paleontological data on such relatively short warm periods are especially important. That is why they should be thoroughly documented and correctly interpreted.

† Deceased.

Regional stratigraphic scheme of the Quaternary (Pleistocene) deposits of Belarus and their correlation with the adjacent territories

Age, Ma	System	Unit	Suggested scheme	Regional standard stratigraphic scheme for Belarus, 1982	Central regions of Russia (Breslav *et al.*, 1992)	Poland (Mojski, 1985, 1993)
	Quaternary	Holocene	Holocene	Holocene	Holocene	Holocene
0.01		Neopleistocene	Poozer'e	Poozer'e	Valdai: Ostashkov / Monchalovo / Kalinin	North Poland (Visla)
			Murava	Murava	Mikulino	Eem
0.13			Dnieper	Sozh	Podmoskov'e: Moscow	Middle Poland (Odra)
				Shklov		
				Dnieper		
		Mezopleistocene	Aleksandriya	Aleksandriya	Likhvin	Mazovetskie
			Berezina	Berezina	Michurinsk: Oka	Vilga (San II)
			Mogilev	Belovezh'e	Michurinsk: Muchkap	Ferdinandov
			Nizhninskii			
			Belovezh'e			
			Minsk: Yasel'da	Narev	Michurinsk: Don	South Poland
			Minsk: Korchevo		South Voronezh: Il'inka	Pshasnysh
			Minsk: Narev		South Voronezh: Pokrovka	Narev
0.73		Eopleistocene	Brest: Smorgon'	Brest	South Voronezh: Petropavlovsk	Eopleistocene
			Brest: Ruzhany		Horizons have not been defined	
			Brest: Varyag			
			Gomel': El'nya			
			Gomel': Vselyub			
1.65	Pliocene		Dvorets			

Taking into account the complicated and contradictory lithological data on the number and distribution of the Pleistocene glacial horizons in Belarus, one should pay special attention to the glacial deposits, mainly, moraines in those reference stratigraphic sections where they could be reliably dated due to a clear lithogenetic connection with overlying interglacial beds of known age. Despite the limited factual material of this kind, it seems that there is still no other way to distinguish effective and scientifically grounded lithostratigraphic complexes.

System and series are subdivisions of the general stratigraphic scheme of the Anthropogene, and the superhorizon and horizon are its regional units. The Quaternary System of Belarus includes four subdivisions: Eopleistocene, Mezopleistocene, Neopleistocene and Holocene (table). The estimated age of the Eopleistocene lower boundary is about 1.65 Ma. The base of the most ancient Narev glaciohorizon of Belarus is suggested to be the Eopleistocene–Mezopleistocene boundary. The Neopleistocene lower boundary coincides with the base of the Dnieper glaciohorizon. The lower limit of the Holocene is suggested to be 10 ka old. In order to facilitate geological mapping in those regions where the Eopleistocene and lowermost Mezopleistocene horizons are incompletely represented, we decided to unite them into superhorizons.

In Belarus, the chronological range of the Eopleistocene is about 0.92 Ma, thus exceeding that of the Glaciopleistocene (Mezo- and Neopleistocene) by nearly 200 ka. It corresponds to the part of the lower Pleistocene of Western Europe from the Eburonian to the first Cromerian interglacial, including marine climatic stages from 36 to 20. In the Russian plain, the Eopleistocene corresponds to the Apcheronian Stage and its continental analogues: the Domashkinskie Vershiny, Boshernitsa, Zhevakhova Gora and Morozovka horizons (Nikiforova, 1987). The morainic, limno- and fluvioglacial deposits are absent in the Eopleistocene sections of Belarus, but there is evidence of loess formation and weathering under cold and dry climate. The Eopleistocene deposits of Belarus are mainly represented by lacustrine, and sometimes by alluvial facies. Silts (fine sandy loams), bluish and greenish-gray, dusty, sometimes calcareous, and clays, gray, greenish-grey, and dark grey, partly laminated, with an admixture of quartz and feldspar–quartz sands predominate among these deposits. Clays and sandy loams are sometimes replaced by organogenic and humic sediments—gyttjas, peats, humic silts and clays. Alluvial facies consist of laminated sands, clays, and humic sandy loams which sometimes contain peat.

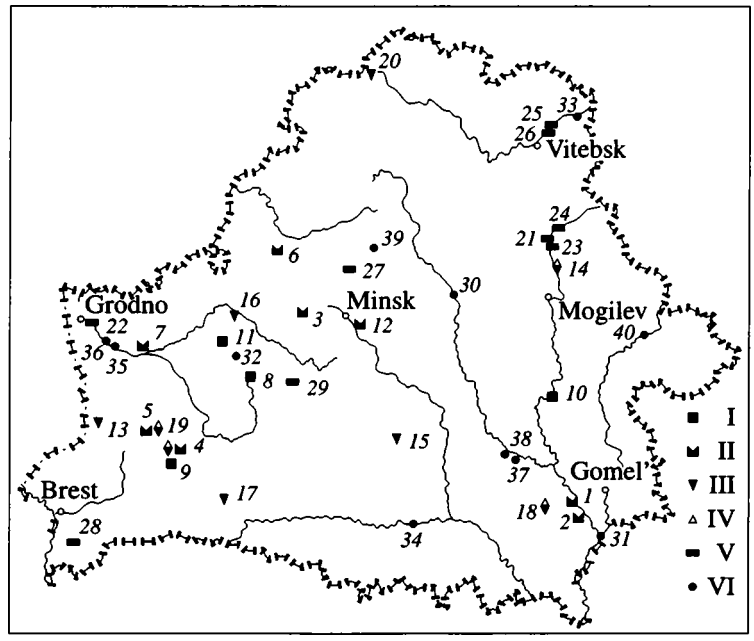
The total thickness of the Eopleistocene deposits varies from 1 to 30 m. It grows up to 50 m at the slopes of glacial grooves (near settlement of Kossovo), or in the zones of predominant subsidence like those near the village of Balazhevichi, the Mozyr' region (*Neotektonika* ..., 1984). The depth of their upper boundary also varies from 4.5–8 m in the southern part of the Pripyat' depression to 160–260 m within the Belarussian anteclise.

Geological and spatial distribution of the Eopleistocene beds has the following peculiarities. The lower Eopleistocene deposits are rare, but they usually overlie the Pliocene sediments without unconformity, and are mainly restricted to the river valleys of the Dnieper and Neman basins occupying distribution areas of the Pliocene beds (the villages of Dvorets, Kholmech Vselyub, and other localities). The upper Eopleistocene horizons are restricted to the zone previously occupied by the first glacial cover. Here they occur in association with the most ancient moraine without resting upon the Neogene deposits. They are mainly found in southwestern Belarus and adjacent territories of Lithuania (figure).

The Vselyub Horizon. The name was suggested by Goretskii (1980) for the upper Pliocene alluvial formation of Poneman'e. Yakubovskaya and Nazarov (1993) used it to designate the most ancient Eopleistocene horizon. The horizon includes the Verkhnii Dvorets and Vselyub formations. The Kholmech-3 section along the Dnieper River represents its holostratotype. The parastratotype corresponds to the interval of 45.2–62.0 m in the drill hole 107 near the village of Krivichi, the Lida area (Yakubovskaya, 1984). Seed flora from this section (from the depths of 59.0–59.5 m) contains *Pilularia pliocenica, Selaginella selaginoides, Potamogeton vaginatus, Carex paucifloroides,* and other species common to the flora of the Kholmech-3 section and other sections of the Verkhnii Dvorets Formation. Fragmentary spore-and-pollen spectra from drill hole 120 near the village of Lozy and drill hole 119 near the village of Detomlya, the Novogrudsk area, correspond to the *Betula–Pinus–Artemisia*–Poaceae palynoassemblage (Rylova, 1980). Palinograms for sections of stripping 14-k near the village of Dvorets and bore pit 2a near the village of Kholmech, the Rechitsa region, exemplify the *Betula*–Poaceae–*Artemisia* and *Artemisia–Betula–Pinus–Salix* palynoassemblages (Zinova *et al.*, 1987). Fossil entomofauna of the Vselyub Horizon was studied in eight sections, and suggests cold and wet climatic conditions. Species of the taiga zone predominate,while species ecologically connected with arboreal vegetation are absent. At least three climatic warmings similar to the present climatic conditions of the southern taiga zone occurred during the accumulation of this horizon. Together with modern species, sclerites of exotic Coleoptera (*Clivina* sp., *Otiorhynchus* sp., *Cercyon* sp., and Lathridiidae gen.) were recorded here. These forms comprise about 10% of the total species composition of the paleoentomofauna. The assemblage consisting of such species as *Patrobus* cf. *assimilis, Notaris aethiops*, *Hydromus alismatis*, and *Epaphius rivularis* characterize the cold episodes of the Vselyub epoch; and the assemblage including *Notaris bimaculatus*, *N.* cf. *acridulus, Pterostichus minor, Elaphrus riparius,* and *Cytilus sericeus* is typical of warm intervals.

The *El'nya Horizon* was described by Voznyachuk (1981) as an analogue of the Waalian Horizon of Europe: it is named after the El'nya Creek in the Shchara River basin. Its holostratotype is recovered in the creek flood-plain by drill hole 141 near the village of Mikelevshchina, the Most area. The peat layer underlying the most ancient moraine and overlying the Cretaceous rocks was found in the interval of 157.7–159.2 m. Goretskii (1973) thought this peat to be an erratic mass; control drilling later confirmed this supposition. The peat contains small, but very expressive seed flora of *Brasenia belorussica, Aracites johnstruppii,* and *Stratiotes* sp., corresponding to one of the warmest Eopleistocene periods. This is also evident from the *Quercus–Pinus–Betula* palynoassemblage distinguished by N.A. Makhnach. The layer of peaty sapropelite with the flora of the El'nya type (*Aracites johnstruppii, Stratiotes* cf. *brevispermus, Carex paucifloroides, Scirpus atroviroides,* and *Decodon goretskyi*) found at a depth of 32 m in drill hole 7173 near the village of Bukcha, the Lel'chitsy area (Yakubovskaya, 1989), has a more definite stratigraphic position—between the Pliocene Dvorets Horizon and the Brest Superhorizon.

Varyag Horizon. The name was suggested by Voznyachuk for the most ancient Glaciopleistocene



Location of the Pleistocene reference sections in Belarus. I, Eopleistocene: (*1*) Dvorets, (*2*) Kholmech, (*3*) Tesnovaya, (*4*) Smolyarka, (*5*) Verchitsy, (*6*) Krevo, (*7*) Mikelevshchina; II, Korchevo interglaciation: (*8*) Korchevo, (9) Postolovo, (*10*) Khimy, (*11*) Romanyuki, (*12*) Machulishchi; III, Belovezh'e interglaciation: (*13*) Borki, (*14*) Nizhninskii Rov, (*15*) Kosteshi, (*16*) Nikolaevo, (*17*) Motol', (*4*) Smolyarka, (*18*) Krasnaya Dubrova, (*19*) Yatvez', (*20*) Obukhovo; IV, Mogilev interglaciation: (*4*) Smolyarka, (*14*) Nizhninskii Rov, (*18*) Krasnaya Dubrova, (*19*) Yatvez'; V, Malaya Aleksandriya interglaciation: (*21*) Matveev Rov, (*22*) Kolodezhnyi Rov, (*23*) Rudakov Rov, (*24*) Starye Staiki, (*25*) Gralevo, (*26*) Ruba, (*27*) Laperovichi, (*28*) Gvoznitsa, (*29*) Minichi; VI, Murava interglaciation: (*30*) Murava, (*31*) Loev, (*32*) Timoshkovichi, (*33*) Chernyi Bereg, (*34*) Doroshevichi, (*35*) Knyazhevodtsy, (*36*) Bogatyrevichi, (*37*) Svetlogorsk, (*38*) Boroviki, (*39*) Kuzevichi, (*40*) Cherikov.

glaciation, which was later renamed as Narev. The lectostratotype of the horizon corresponds to the interval 63.5–72.4 m in drill hole 13 near the village of Smolyarka, the Bereza area (Voznyachuk *et al.*, 1971; Yakubovskaya and Rylova, 1992). The flora indicating the nearly glacial climate comes from the interlayers of sandy silt and fine sand with timber remnants (64.0–65.4 m). It includes *Selaginella selaginoides, S. helvetica, Potamogeton vaginatus, Betula* cf. *humilis*, and other arctic-boreal and typical eurythermal species. Previously, P.I. Dorofeev found similar flora in drill hole 190 near the village of Grushevo (depth 42.8 m), and drill holes 168 (44.8–45.6 m) and 157 (45.0–46.0 m) near the village of Rozhok, the Drogichin area. The *Betula–Alnus–Artemisia*–Poaceae–Cyperaceae palynoassemblage distinguished by T.B. Rylova corresponds to the coldest period of the accumulation time of this horizon. It was preceded by the *Betula–Pinus–Artemisia*–Chenopodiaceae–Poaceae palynoassemblage. *Pinus* is the dominant form in the spore-and-pollen spectra of the upper Varyag beds. The appearance of *Azolla interglacialis* and *Stratiotes intermedius* in the seed flora from this part of the section indicates slight climatic warming and marks the transition to the overlying horizon. P.I. Dorofeev studied similar floras in drill holes 136 near the village of Rozhok (interval 46.5–49.6 m), 323 near the village of Bronnaya Gora (depth 65.0 m), and 343 near the village of Verchitsy (depth 83.0 m).

Ruzhany Horizon. Its holostratotype corresponds to the 75.0–81.0 m interval in drill hole 343 near the village of Verchitsy, 15 km away from the settlement of Ruzhany, the Ruzhany area. Studying the layer of intercalating clays, silts and sands at the depth of 78 m P. I. Dorofeev described flora consisting of *Brasenia nehrinhii* (=*B. belorussica*), *Scirpus kreczetoviczii, Stratiotes aloides, Lemna trisulca,* and other thermophilic herbaceous species of aquatic or boggy type. Similar floras were distinguished in drill holes 328 near the village of Bronnaya Gora (interval 74.0–75.0 m), 391 near the village of Likhosel'tsy, the Pruzhany region (interval 108.5–111.0 m), and 7173 near the village of Bukcha, the Lel'chitsy area (depth 28.0 m). These intervals yielded the *Pinus–Quercus–Betula–Alnus* palynoassemblage distinguished by A.F. Burlak in the upper part of the interval 71.0–83.0 m in the stratotypical section of drill hole 343. Fossil entomofauna of the Ruzhany epoch was studied in drill holes 8, 17, and 31 near Drochinin, and 391 near the village of Likhosel'tsy, the Pruzhany area. It includes rare remnants of *Chlaenius tristis, Gerris* sp., *Psammobius* (*Rhyssemus*) *germanus, Denacia clavipes, Plateumaris braccata,* and other species. The presence of *Chlaenius*

tristis shows that during accumulation of this horizon, climatic conditions were warmer than at present.

The *Smorgon' Horizon* was distinguished by Goretskii (1980) near the town of Smorgon'. It corresponds to the Brest Horizon of Makhnach (1971) and the Sivkovo Formation. The interval 153.0–175.7 m in drill hole 019 near the village of Krevo, the Smorgon' area, was suggested as the lectostratotype. Palynological (Makhnach, 1977) and geochemical (Bobrova *et al.*, 1977) analyses of this interval revealed intricate climatic rhythmics reflected in the multiple alternation of *Pinus* and *Betula* pollen maxima, and some other peculiarities of the palynological diagram. The *Pinus–Betula–Artemisia* and *Artemisia–Betula* palynoassemblages from the interval 171.0–175.0 m and predominance of herbs in the spectra from its upper part seem to be indicators of the climatic conditions close to the glacial stage.

T.B. Rylova's palynological data on drill hole 017 near the village of Kiseli, the Minsk area, revealed similar patterns of the evolution of vegetation during the Smorgon' time. The diagram for sediments in the interval of 159.5–180.3 m displays five cold phases corresponding to the periglacial environment, and four warmer phases reflecting forest vegetation with the predominance of pine trees.

Seed flora of the Smorgon' time was reported from the interval of 70.0–79.0 m in drill hole 032 near the village of Naroch', the Vileika area. The impoverished taxonomy and presence of cold-resisting forms *Selaginella selaginoides, Potamogeton vaginatus*, and *Carex caespitosa* are its characteristic features. P.I. Dorofeev reported similar floras with *Picea* sp., *Betula nana*, polar species of *Salix* from deposits underlying moraine in the Brest depression.

Fossil entomofauna of the Smorgon' deposits includes dwellers typical of current tundra and open landscapes. It shows a combination of the following forms: *Notiophilus aquaticus, Diacheila* aff. *arctica, Bembidion* (*Peryphus*) sp. exot., *Pterostichus* aff. *haematopus, Helophorus obscurellus, Simplocaria metallica, Morychus michaylovski, Notaris bimaculatus*, and *N. aethiops*. The specific taxonomic composition, absence of mountainous-steppe forms, and first appearance (within Eopleistocene) of tundra species allow this fauna to be considered as periglacial.

Narev Horizon. Voznyachuk suggested this name (after the Narev River) for the moraine underlying the Belovezh'e interglacial deposits in the stratotypical Borki section situated in the Belovezhskaya Pushcha. Originally, he considered the latter to be the most ancient of interglacial deposits. When the Korchevo interglacial beds were described, Voznyachuk used the initial term for the underlying moraine, and here we use it to designate the most ancient moraine of Belarus. In its normal stratigraphic position, the Narev moraine was observed in the following sections: in drill hole 107 near the village of Machulishchi (interval 130.5–136.0 m) of the Minsk region (Komarovskii and Yakubovskaya, 1988), in some drill holes of the Bereza stratoregion (Velichkevich *et al.*, 1993), in the drill holes of the Soligorsk region (Tsapenko and Makhnach, 1959; Kriger, 1967; Makhnach, 1971, and others), in the drill hole near the village of Ugly situated between the towns of Parichi and Bobruisk (Tsapenko and Makhnach, 1966), and in the quarry near the village of Korchevo, the Baranovichi region, where the Korchevo interglacial beds together with the underlying moraine are exposed at the surface in response to intense glaciodislocations (Voznyachuk *et al.*, 1977; Zus', 1991, and others).

The Narev moraine is usually represented by thin beds of greenish-gray, dark-brown, and dark-gray boulder and sandy loams overlying beds of different age (from Eopleistocene–Pliocene to Devonian and Proterozoic). The Narev moraine shows a complicated and rich mineral association, which appeared due to direct denudation of various preglacial beds by the most ancient glacier. Assuming that in all the aforementioned localities, the relations between the Korchevo interglacial beds and underlying Narev moraine are undisturbed, we estimated that the maximum limit of the Narev glaciation probably coincides with the northern part of the Poles'e lowland. The exaration eliminated the moraine in many localities, and only its rare remnants and indiscriminated fluvioglacial and periglacial sands, sandy loams, and clays were preserved.

Korchevo Horizon. Its holostratotype is represented by the ancient lacustrine interglacial beds exposed in an open pit near the brick-yard situated at the left bank of the Servech' River (the left tributary of the Neman River) between the villages of Korchevo and Elizarovshchina, the Baranovichi area, about 6 km eastward of the Gorodishche Settlement (Voznyachuk *et al.*, 1977, 1978). The interglacial sequence displays an alternation of clayey and peaty gyttjas with dark-gray loams humified to different degrees. The Korchevo interglacial layers were also found in several drill holes: near the village of Machulishchi of the Minsk district (Komarovskii and Yakubovskaya, 1988), near the village of Romanyuki near the town of Novogrudok (Nazarov, 1990), near the village of Postolovo, the Bereza area (Velichkevich *et al.*, 1993), and near the village of Khimy, the Rogachev area (Velichkevich and Rylova, 1988).

Palynological diagrams for the stratotypical section of the Korchevo interglacial beds show the following characteristic features: pollen of *Quercetum mixtum, Alnus* and *Corylus* appears nearly simultaneously, prior to that of *Carpinus* (max. 12%); *Quercus* grains predominate over pollen of other broad-leaved species (max. 24%); *Corylus* pollen is not abundant in the sediments corresponding to the climatic optimum (up to 8–9%); pollen of *Taxus, Pinus strobus, P.* sect. Cembrae, and *Picea omorica*, spores of *Selaginella* similar to those in the Dvorets Formation, and massules of *Salvinia* and *Azolla* are rare. Specific seed flora of the

Korchevo time includes the following extinct herbaceous species: *Azolla interglacialis, Potamogeton perforatus, P. dvinensis, P. pseudorutilus, P. panormitanoides, Alisma minima, Stratiotes* cf. *intermedius, Scirpus atroviroides, S. kreczetoviczii, Eleocharis praemaximowiczii, Carex paucifloroides, Caulinia antiqua, Ranunculus sceleratoides, Aldrovanda zussii,* and others.

According to Motuzko (1985), the small mammal fauna from the Korchevo section includes the following species: *Trogontherium* sp., *Mimomys intermedius, Microtus ratticepoides, M. nivaloides, M.* aff. *gregalis, M.* ex gr. *hyperboreus-middendorfii, Microtus* sp., *Pitymys hintoni, Clethrionomys* aff. *glareolus* and others. *Mimomys intermedius* is the index species of this assemblage, and gray rootless voles are associated forms.

Malacofauna of the Korchevo section is represented by *Bithynia labiata, Pisidium astartoides, Lithoglyphus* cf. *piramidatus, Gyraulus albus, Valvata cristata* and others (32 taxa in total).

Fossil entomofauna of the Korchevo section consists of thermophilic species *Chlaenius tristis, Oodes helopoides, Pterostichus melanarius, Odocantha melanura, Colymbetes paukulli, Donacia obscura,* and *Hydronomus* associated with extinct *Morychus michaylovski, Dorcadion* sp., *Rhysophagidae* gen., and *Anthicidae* gen.

The *Yasel'da Horizon* was named after the Yasel'da River (the left tributary of the Pripyat' River), where its deposits are widespread (Velichkevich *et al.*, 1993). The latter are represented by glacial, fluvioglacial, and periglacial beds, which have close connections with the overlying Belovezh'e interglacial deposits. Morainic sandy loams and loams are the most important rock types. They exceed the Narev moraine in thickness and distribution area. This is the thickest moraine in southwestern Belarus where it represents the key horizon of the Pleistocene sequence. The southernmost localities of the Yasel'da moraine and Belovezh'e deposits occur near the Ivatsevichi–Starobin–Rechitsa line, which may be considered as the maximum southern limit of the Yasel'da glaciation. In most of the drill holes of central and northern Belarus, the Yasel'da moraine underlies the Belovezh'e deposits at depths of about 70–100 m. At the same time, in most southern areas this moraine can be found close to the surface. For instance, near the town of Bereza,a large body of the Yasel'da–Belovezh'e deposits was found in the depth range of 10–40 m. In the Lyuban' region (Kosteshi section), the Yasel'da moraine is exposed to the day surface. The Yasel'da glacial deposits are mainly represented by dense gray, sometimes dark-gray morainic sandy loams with sandy lenses and interlayers. The Yasel'da moraine contains many detached fragments of the Cretaceous and Paleogene rocks, which sometimes occur in a frequent alternation with boulder and sandy loams responsible for the imbricated aspect of the sequence. In contrast to the younger moraines, the gravel fraction of the Yasel'da moraine is rather rich in sedimentary rock debris, while volcanic and metamorphic rock fragments are less abundant.

Tundra ground beetles including *Diacheila polita* Gyll., *Pterostichus* (*Cryobius*) spp. and other species were found in the periglacial beds underlying the Yasel'da moraine. Diverse tundra entomofauna (*Diacheila polita* Gyll., *Bembidion* (*Peryphus*) *dauricum* Motsch., *Pterostichus* (*Stereocerus*) *haematops* Bej., *P.* (*Lyperopherus*) *vermiculosus* Men., and *P.* (*Cryobius*) ex gr. *pinguedineus* Eschsch., *Lepyrus nordenskjoeldi* Faust, and others) was reported from the beds overlying the moraine. This fauna shows that the periglacial environment remained long after the glacier's retreat. Extinct subspecies of ground beetles *Pterostichus ravus* Lutsch of the *Derus* subgenus now occurring in the mountains of the Transbaikal region and Mongolia are also characteristic of these beds.

Belovezh'e Horizon. Its holostratotype is represented by the ancient interglacial lacustrine sediments, mainly calcareous gyttjas, occurring in the interval of 87.0–110.5 m in drill hole 153 situated in the Belovezhskaya Pushcha at the eastern outskirts of the village of Borki, the Pruzhany region. The sequence overlies thin Yasel'da moraine, and is, in turn, overlain by the glacial Berezina and Dnieper beds (Voznyachuk, 1961, 1981; Voznyachuk and Puzanov, 1966). Control drilling in 1980 and 1989 revealed the complex paleobotanic characteristic of the section and the neostratotype in drill hole 2G (Yakubovskaya *et al.*, 1991). In Belarus, the Belovezh'e interglacial deposits were reported from dozens of sections. The following sections are the best studied: drill hole 13B near the village of Krasnaya Dubrova, the Rechitsa area; drill hole 13 near the village of Smolyarka; drill hole 1279 near the village of Strigin and drill holes 1474 and 5 near the village of Golitsy, the Bereza area; drill hole 9 near the farm of Yaglevichi and drill holes 1885 and 6 near the village of Yatvez', the Ivatsevichi region; the Nizhninskii Rov outcrop near the town of Shklov; the Kosteshi outcrop of the Lyuban' region; the Obukhovo outcrop at the Sar'yanka River, the Verkhnedvinsk region; the Motol' outcrop of the Ivanovo region; and many others. Palynological analysis revealed the following succession of vegetation assemblages during the Belovezh'e interglaciation: bl_1—birch–coniferous (birch–larch–spruce–pine) and coniferous–birch forests; bl_2—pine–birch forests with larch, spruce, alder, broad-leaved species, and hazel; bl_3—mixed broad-leaved–coniferous (oak–elm–pine) forests with birch and alder; bl_4—broad-leaved (oak–elm–lime–maple–ash) forests with pine, birch, spruce, or broad-leaved–coniferous forests with a well developed hazel undergrowth and alder thickets at wet lowlands; bl_5—broad-leaved–spruce–fir forests with a well-developed hazel undergrowth with alder; bl_6—pine or spruce–pine forests with birch, alder, and broad-leaved species (oak, elm, lime); bl_7—pine and pine-spruce forests with birch; bl_8—coniferous–

microphyllous forests with abundant herbaceous assemblages in open landscape.

According to the data of paleocarpology, exotic herbaceous plants of the Belovezh'e time are represented by the following species: *Potamogeton sarjanensis, P. panormitanoides, Caulinia macrosperma, C. interglacialis, Stratiotes brevispermus, Scirpus atroviroides, Carex paucifloroides, Brasenia borysthenica, Euryale byelorussica, Nymphaea cinerea, Aldrovanda borysthenica,* and others.

Diatom flora of the Belovezh'e time shows the following features: a high content of the extinct Pliocene–Pleistocene taxa (*Cyclotella radiosa* var. *pliocaenica* up to 30%, and *C. radiosa* var. *lichvinensis* up to 25%); a significant amount of the Belovezh'e interglacial index species (*Cyclotella reczickiae, Stephanodiscus determinatus, S. styliferum, S. raripunctatus, Navicula variabilis,* and *N. jentzschii* f. *kuptzoviae*); abundance of the taxa distinguished in the Belovezh'e flora for the first time and occasionally found in the younger floras (*Cyclotella reczickiae* var. *diversa* up to 46%, *Stephanodiscus peculiaris* up to 22%); and frequent occurrence of *Stephanodiscus niagarae* var. *insuetus*.

Malacofauna of the Belovezh'e interglacial beds includes *Lithoglyphus naticoides, Viviparus* sp., *Pisidium astartoides, P. casertanum,* and other mainly rheophilic species.

Oleoptera (*Pentatoma rufipes, Zicrona caerulea,* and *Ilyocoris cimicoides*), ground beetles (*Bembidion doris, Oodes helopoides, Pterostichus aterrimus, P. nigrita,* and *P. minor*), water-tigers (*Copelatus haemorrhoidalis, Acilius sulcatus,* and *Cybister lateralimarginalis*), and leaf beetles (*Donacia obscura, Plateumaris braccata* and others) predominate in the paleoentomofauna of the Belovezh'e epoch (Nazarov, 1985).

Nizhninskii Rov Horizon. Its holostratotype corresponds to the greenish-gray solifluction sandy loams with pebbles and boulders, which associate with lacustrine silts and sandy loams, enclosing interlayers of sand and gravel, and separate the Belovezh'e and Mogilev interglacial deposits of the Nizhninskii Rov exposure near the town of Shklov (Voznyachuk, 1985). Hypostratotypes of the horizon correspond to the interval of 15.4–18.8 m in drill hole 1474 near the village of Golitsy, the Bereza region (Velichkevich *et al.*, 1993); and to the interval of 31.4–34.4 m in drill hole 55B near the village of Krasnaya Dubrova, the Rechitsa area, (Makhnach and Rylova, 1986; Khursevich and Loginova, 1986). Palynological data of N.A. Makhnach, O.P. Kondratene, and T.B. Rylova bring in evidence of two periods with severe, subarctic climates during the Nizhninskii Rov epoch. These periods are separated by the Golitsy interstadial with forest vegetation of the boreal type (Velichkevich *et al.*, 1993). In the drill hole near the village of Ugly, the Parichi region, two interstadials could be distinguished within the periglacial beds overlying the Belovezh'e beds (Tsapenko and Makhnach, 1966). The lower interstadial corresponds to the Golitsy beds, while the second one represents the individual Ugly interstadial. Palynological assemblages of the Nizhninskii Rov Horizon from the Krasnaya Dubrova section show the absolute predominance of *Betula* pollen (max. 100%) mainly represented by shrub forms and significant amounts of *Artemisia* (up to 84%), *Poaceae* (up to 22%), *Chenopodiaceae* (up to 34%), and *Asteraceae* (up to 7%) pollen associated with grains of *Ephedra, Helianthemum* and other herbaceous plants typical of the open and ruderal landscapes. Diatom flora of the Nizhninskii Rov time is represented by extremely small, undoubtedly stunted, sometimes deformed specimens of littoral species (*Opephora martyi, Fragilaria brevistriata,* varieties of *F. construens, Amphora pediculus,* and *Navicula scutelloides*), indicating periglacial climatic conditions.

The formation of the Nizhninskii Rov periglacial layers is connected with relatively small glaciation, which probably did not reach the territory of Belarus. We correlate sediments of the Nizhninskii Rov Horizon with periglacial layers separating deposits of the Glazov and Konakhovka Formations of the Roslavl' stratoregion of Russia (Biryukov *et al.*, 1992), and also with the similar layers of the Zhidini section in Latvia (Kondratene *et al.*, 1985), and the Ferdinandov section in Poland (Janczyk-Kopikowa, 1975).

Mogilev Horizon. Its holostratotype corresponds to the upper layer of the buried peat in the Nizhninskii Rov section exposed along the Dnieper River near the town of Shklov (Voznyachuk, 1981). Hypostratotypes of the horizon correspond to the interval of 22.8–28.0 m in drill hole 13B near the village of Krasnaya Dubrova, the Rechitsa region (Makhnach *et al.*, 1982; Makhnach and Rylova, 1986); to the interval of 14.0–15.5 m in drill hole 3 near the village of Smolyarka, the Bereza region; and to the interval of 64.9–67.5 m in drill hole 25 near the village of Pushkari, the Vitebsk region. Among the numerous palynological diagrams obtained for N.A. Makhnach, Ya.K. Elovicheva, O.P. Kondratene, T.B. Rylova, and others, the Nizhninskii Rov interglacial beds, that of the stripping 2 (Kondratene and San'ko, 1985) displays the most complete patterns of the vegetation evolution during the Mogilev interglaciation. This diagram shows four palynological assemblages consisting of birch–larch–pine (XII), oak–elm–lime (XIII), hornbeam–oak–elm–lime–spruce–pine (XIV), and birch–pine–larch (XV) species. Taxonomy and content of exotic seed species from the Mogilev Horizon in the Nizhninskii Rov section are close to those of the Belovezh'e interglacial flora. However, the Mogilev flora contains abundant remnants of *Carpinus* cf. *betuloides, Brasenia borysthenica* s.s, and *Hypericum pleistocenicum*, which are rare in the underlying Belovezh'e flora. There are several other differences between the Mogilev and Belovezh'e floras, mainly concerning the abundance of index species. Planktonic species of the *Aulacoseira* and *Stephanodiscus* genera predominate in the diatom assemblage of the Mogilev time studied in the Krasnaya Dubrova section. Here,

the extinct species *S. niagarae* var. *insuetus* predominates among species of the *Stephanodiscus* genus, while *S. rotula* and *S. parvus* are less abundant, and *S. styliferum* typical of Belovezh'e beds is absent. Species of the *Cyclotella* genus are not numerous; *C. radiosa* var. *pliocaenica* is represented by single valves, and *C. reczickiae* is absent. Paleoentomofauna of the Mogilev time includes *Epaphius rivularis, Pterostichus nigrita, P. minor, P. diligens, Notaris aethiops, Donacia obscura, Lixus iridis, Clivina fossor, Bembidion,* and others.

Berezina Horizon. Lepikash (1936) and Bilenko (1936) were the first to distinguish this unit. Within the area of the Dnieper headwaters, these authors placed the Berezina glacial sediments below beds of the Dnieper and Orsha glaciations. Deposits of the Berezina Horizon are correlative with the Mindel glaciation of G.F. Mirchink, the Oka glaciation of K.K. Markov, the Likhvin glaciation of N.N. Sokolov and V.P. Grichuk, the glaciations of the second half of the ancient epoch of M.M. Tsapenko and N.A. Makhnach, the Upper Berezina glaciation of G.I. Goretskii, the Elster glaciation in Germany and England according to P. Volshtedt, and the Dainava glaciation in Lithuania according to V.P. Vonsavichus. The Berezina Horizon of Belarus represents a complicated association of the glacial, fluvioglacial, and periglacial deposits. Moraines are dominant rock types among them. Their spatial distribution and relations with the Malaya Aleksandriya lacustrine beds filling the glacial–karst depressions suggest that the Berezina glacier occupied the largest part of the Belarus territory. There are several opinions suggesting the similar position of the southernmost limit of this glaciation (Tsapenko and Makhnach, 1959; Voznyachuk *et al.*, 1971; Gurskii, 1971; Matveev, 1990). The Berezina moraine is represented by coarse, dense sandy loams and loams, with numerous lenses and interlayers of inequigranular sands, clays, boulders, and pebbles. The moraine is usually gray with a greenish or bluish tinge. It usually contains erratic blocks of the Cretaceous, Paleogene and Neogene rocks. The moraine frequently has an imbricated outlook, especially at the slopes of glacial hollows. The total thickness of the morainic horizon is 20–30 m, reaching 70–80 m at the slopes of glacial hollows and in separate slices.

The content of coarse detritus in the moraine is usually relatively low (8–10%). Sedimentary rocks predominate among gravel and pebbles: limestones and dolomites in the central and western regions, and Paleogene sandstones and siltstones in the eastern ones. Granites, gneisses, and porphyries are typical representatives of the crystalline rocks. Quartz predominates in the mineralogical composition of the fine sand fraction. The content of amphiboles, pyroxenes and other unstable minerals is insignificant. Montmorillonite and chlorite are present in the clayey fraction.

Malaya Aleksandriya Horizon. Its holostratotype is represented by the interglacial sediments exposed in the Matveev Rov gully situated at the right bank of the Kopysitsy River (the right tributary of the Dnieper River) near the southeastern edge of the village of Malaya Aleksandriya, the Shklov area (Goretskii, 1970; Makhnach, 1971). The parastratotype corresponds to the interglacial lacustrine, lacustrine-bog, bog, and lacustrine-alluvial deposits exposed in the Kolodezhnyi Rov gully near the former village of Prinemanskaya (previous name— Zhidovshchizna), 4 km eastward from the town of Grodno (Yakubovskaya, 1976). Numerous palynological diagrams of the Malaya Aleksandriya interglaciation show the following features: a high abundance of the *Picea* (up to 80%) and *Alnus* (up to 80%) pollen at the beginning of the interglaciation; abundant coniferous pollen (pine, spruce, fir) during the whole interglaciation; simultaneous or nearly simultaneous appearance of the broad-leaved (oak, lime, elm, and others) and hazel pollen; later and nearly simultaneous appearance of the *Abies* (up to 80%) and *Carpinus* (up to 40%) pollen; low, but persistent content of exotic pollen (*Vitis, Pterocarya, Buxus, Ligustrum, Pinus* subgen., and *Haploxylon*). Seed flora of the Malaya Aleksandriya time displays a predominance of coniferous (especially dark coniferous *Picea, Abies alba,* and *Taxus buccata*) species among arboreal forms, and abundance of extinct species and intraspecific taxa (*Aracites interglacialis, Myriophyllum spinulosum, Gaulinia goretskyi, Aldrovanda dokturovskyi, Brasenia borysthenica* var. *nemensis, B. b.* var. *heterosperma,* and others) among the herbaceous plants. These forms are absent or rare in the floras of other glaciations. The high abundance and significant taxonomic diversity of the *Cyclotella* genus (up to 30 species and varieties) distinguish the Malaya Aleksandriya diatom flora from more ancient and younger ones. *Cyclotella radiosa* var. *lichvinensis, C. parvula,* and *C. temperiana* are its age–indicators. The content of the more ancient taxa *C. radiosa* var. *pliocenica* and *Stephanodiscus niagarae* var. *insuetus* is relatively small (up to 4 and 150 correspondingly). The index species *Stephanodiscus fascicularis* and *S. immemoratus* var. *minor* are responsible for the original character of the flora.

Fossil entomofauna of the thermal maximum of the Malaya Aleksandriya interglaciation sharply differs from other interglacial assemblages. This is evident from the constant presence of the boreal species (*Epaphius rivularis* and *Notaris aethiops*) associated with the thermophilic exotic forms (*Agonum holhausi*) indicating episodes of a drier and warmer climate. The characteristic assemblage of the Malaya Aleksandriya time includes: *Cychrus caraboides, Patrobius excavatus, Plateumaris sericea, Sitona hispidulus, Hylobius pinastre, Notaris acridulus,* and *N. aethiops*. The constant presence of the species typical of coniferous forests is another characteristic feature of this fauna.

Viviparus diluvianus and *Lithoglyphus piramidatus*, which probably became extinct by the end of this glaciation, should be presently considered as a characteristic molluscan species of the Malaya Aleksandriya time.

Dnieper Horizon. The stratotype area of the Dnieper Horizon corresponds to the geographic range of first subsurface glacial deposits in central and south Belarus. In the northern regions, the Dnieper deposits are overlain by the Poozer'e glacial sediments. Spatial distribution of the Dnieper moraines and fluvioglacial deposits shows that the Dnieper glacier covered the whole territory of Belarus. During the maximum glaciation, the edge of the glacial cover reached the territory of Ukraine, several hundred kilometers to the south from the southern Belarus boundary. The structure of the Dnieper Horizon differs from that of the other Pleistocene glacial horizons and includes two moraines corresponding to the first (Dnieper or Drente) and second (Moscow, Sozh', or Varta) megastadials. However, the structure and bedding of the lower and upper Dnieper deposits resemble those typical of the rocks displaying the same status among subdivisions of the other glaciations. For instance, the lower Dnieper sequence of the Kopyl'skaya Range includes layers marking at least two interstadial warmings (San'ko *et al.*, 1989). According to Velichkevich, the upper Dnieper deposits in some other localities of Belarus (Loev, Zhukevichi, and Murava) include the Loev beds (Velichkevich, 1982). Their bedding resembles that of the Dryas beds of the late Poozer'e glaciation. The middle Dnieper sequence includes the intermorainic, mainly fluvioglacial deposits separating two stadial moraines. This is especially typical of the area between the boundaries of the Sozh and Poozer'e glaciations. In the Belarussian Poozer'e, the intermorainic deposits thin out, and the Dnieper glaciation is represented by an indivisible morainic sequence. For instance, in the Gralevo region, such a sequence lies between the Malaya Aleksandriya and Murava interglacial sediments (San'ko and Motuzko, 1982). Outside the limits of the Sozh stadial, the Dnieper morainic deposits occur as separate patches even in regions close to the limit of this stadial near the town of Bereza, the Brest region (Velichkevich *et al.*, 1993). The whole thickness of the Dnieper Horizon varies significantly. It is at the maximum (100 meters and more) in the Belorussian Range, and significantly decreases northward and southward. The Dnieper moraine contains abundant blocks of pre-Pleistocene rocks. Among them, there are many "index" boulders from Fennoscandia. The quite similar composition of the fine sand fraction of both the lower and upper moraines considerably differs from that of the Berezina and Poozer'e moraines (Lukashev and Astapova, 1971). Sublatitudinal marginal forms reflecting the sectoral-zonal structure of the glacial cover were formed during degradation of the Dnieper glacier.

Murava Horizon. Its neostratoype corresponds to the oxbow-lake deposits exposed in the Chertov Kust section at the right bank of the Berezina River near the eastern edge of the village of Poberezh'e, the Borisov area (Val'chik *et al.*, 1989). The palynological diagram of the section plotted by I.E. Krasavina displays nine palynological assemblages. The lowermost assemblage evidences the climatic conditions of the final stage of the Dnieper glaciation, while the other eight characterize vegetation of the Murava interglaciation. The assemblages are as follows: mr_1—pine–birch forests with admixture of spruce; mr_2—pine–birch forests with admixture of broad-leaved species; mr_3—broad-leaved–coniferous (oak, oak–elm with pine) forests with appeared hazel; mr_4—broad-leaved forests consisting of oak, elm, and hazel with admixture of lime and alder thickets; mr_5—broad-leaved forests consisting of lime and hazel with admixture of oak, elm, minor hornbeam, and alder thickets; mr_6—broad-leaved hornbeam–lime forests with hazel, appeared spruce, and alder thickets; mr_2—broad-leaved hornbeam or hornbeam–spruce forests with hazel, alder, and minor oak, elm, and lime; mr_8—coniferous spruce and spruce–pine forests. The data of paleocarpology show that the late glacial beds contain the characteristic Loev flora with *Picea obovata, Selaginella selaginoides, Potamogeton alpinus, P. vaginatus, P. filiformis, Arctostaphylos uva-ursi, Myriophyllum spicatum, M. verticillatum,* and other eurythermal and cold-resistant herbaceous plants. The interglacial beds are rich in the remnants of the broad-leaved species (*Carpinus betulus, Acer campestre, Tilia tomentosa, T. platyphyllos*) and thermophilic herbs of the *Brasenia* assemblage (*Brasenia holsatica, Dulichium arundinaceum, Trapa europaea, Aldrovanda vesiculosa, Caldesia parnassifolia, Cladium mariscus, Caulinia flexilis,* and others). The Murava diatom flora shows the absence of many extinct Pleistocene species of the *Cyclotella* and *Stephanodiscus* genera, presence of the Neopleistocene index species *Gomphocybella ancyli*, and slight morphological differences between the Murava species and their modern analogues. Combination of such species as *Cybister lateralimarginalis, Hydrous aterrimus, Oodes gracilis, Coelostoma orbiculare, Dascillus cervinus, Rhysodes sulcatus, Odocantha melanura, Cyrinus distinctus,* and *Phymatopoderus latipennis* is characteristic of the paleoentomofauna of the Murava epoch. Malacofauna of this epoch includes *Dreissena polymorpha, Valvata fluviatilis, Planorbarius corneus, Fagotia acicularis, Lithoglophus naticoides,* and *Theodoxus fluviatilis*. Water vole *Arvicola* aff. *terrestris* and accompanying species *Apodemus* and *Pitymus* aff. *subterraneus* are distinguished among fossil micromammals.

Poozer'e Horizon. The first subsurface glacial layer of the Belorussian Poozer'e represents the stratotype of the Poozer'e Horizon. The stratigraphic range of the Poozer'e glacial deposits in Belarus corresponds to the final (Orsha) megastade of the Poozer'e glaciation. This sequence consists of morainic, frontal morainic and fluvio-glacial deposits. Now, nearly all specialists agree with Voznyachuk's (1956) opinion on the position of the maximum limit of the glacial cover. It coin-

cides with the southern limit of the Belorussian Poozer'e geographic district.

Poozer'e moraines are mainly represented by reddish brown boulder-sandy loams and loams; frontal moraines—by fluvioglacial sands and sandy-gravel material with pebbles and boulders; and limnoglacial deposits—by varved clays, silts, and sands. Different scientists consider the average thickness of the glacial and fluvioglacial deposits to vary from 20 to 30 m. At the same time, special measurements of the thickness of the Poozer'e deposits based upon study of the reference Neopleistocene sections showed slightly different values. For instance, study of 29 sections revealed the average thickness of the Poozer'e deposits in Belarus to be 10.8 m. The average thickness of deposits within the glacial zone is estimated as 15.3 m, that of the periglacial area as 6.3 m, and the average thickness of the Poozer'e moraine is identified as 4.2 m (San'ko, 1989).

According to the data of Lukashev and Astapova (1971), the composition of the rock-forming minerals of the fine sand fraction of the Poozer'e moraine resembles that of the previous (Dnieper) moraine. Heavy fraction of the Poozer'e moraine is rich in minerals of the Scandinavian province. A higher content of biotite and pyroxenes, absence of siderite, and small amounts of pyrite and glauconite are typical features of this fraction. The total amount of the minerals of sedimentary rocks rarely exceeds 15%. The influence ratio of the Scandinavian province is the highest in the Poozer'e moraine as compared to other Pleistocene moraines.

Holocene Horizon. Deposits of the modern rivers, lakes, bogs, and springs, as well as some slope and eolian deposits represent the Holocene beds. Technogenic rocks also abundant within the horizon should also be considered as Holocene deposits. In Belarus, subdivision of the Holocene sequence is based upon its alluvial, bog, and lacustrine deposits. The total thickness of the Holocene alluvial beds including channel, flood plain, and oxbow lake facies varies from 3–5 m for small rivers to 12–15 m for such rivers as the Dnieper, Pripyat', Neman, Berezina, and Sozh. In Belarus, thickness of the Holocene lacustrine sands, muds, and sapropels does not usually exceed 15 m, and the peat-bog deposits are less than 10 m in thickness (Voznyachuk *et al.*, 1971). The Holocene stratigraphy of Belarus is based upon the data of palynology, diatom analysis, carpology, malacology, entomology, study on ostracodes, radiocarbon dating, and other analyses. They provide grounds to recognize all subdivisions of the Blytt–Sernander scheme of the Holocene sequence. Since the Holocene biota is nearly completely represented by the modern species, subdivision of the sequence is based upon climatic stratigraphy.

The suggested stratigraphic scheme is substantiated by very representative, mostly new data. Our purpose was to show in detail the evolutionary stages of a classical area of Quaternary glaciations, thus improving the available basis for geological mapping and prospecting of Pleistocene deposits in Belarus. Unfortunately, some former, out-of-date stratigraphic concepts concerning the reduced range of the Pleistocene, wide interval of the undivided preglacial Brest Horizon, and disregarded Shklov interglacial are still evident here, and require urgent revision. The new scheme rationalizes all recent stratigraphic achievements in neighboring countries, namely in Russia, Lithuania, and Poland. Belarussian biostratigraphers and paleontologists also studied some sections in these countries, and the discordance between our and the modern stratigraphic scales, which are accepted in the adjacent East European regions affected by glaciations, is insignificant and easily removable in the course of joint investigations. It seems to be more difficult to correlate basic stratigraphic horizons of the Pleistocene glacial and periglacial regions distinguished in Eastern and Western Europe. In this aspect, the Belarus territory, with its very complete sequence of Pleistocene deposits, has the most favorable geographic position and may be considered as the key area for creating the universal European scale of Pleistocene stratigraphy.

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REFERENCES

Bilenko, D.K., Results of the Geological Expedition to the Upper and Middle Dnieper in 1935, *Visti Akad. Nauk URSR*, 1936, nos. 7–8, pp. 86–94.

Biryukov, I.P., Agadzhanyan, A.K., Valueva, M.N., *et al.*, Quaternary Deposits of the Roslavl' Stratotypical Region, in *Stratigrafiya i paleogeografiya chetvertichnogo perioda Vostochnoi Evropy* (Quaternary Startigraphy and Paleogeography of Eastern Europe), Moscow: Inst. Geogr. Ross. Akad. Nauk, 1992, pp. 152–180.

Bobrova, L.A., Kuznetsov, V.A., and Shimanovich, S.L., Materials on Geochemical Characteristic of the Most Ancient Lacustrine–Alluvial and Alluvial Deposits of the Byelorussian Poneman'e, in *Pogranichnye gorizonty mezhdu neogenom i antropogenom* (Transitional Horizons from Neogene to Anthropogene), Minsk: Nauka i Tekhnika, 1977, pp. 243–254.

Breslav, S.L., Valueva, M.N., Velichko, A.A., *et al.*, Stratigraphic Scheme of the Quaternary Deposits in the Central Regions of Eastern Europe, in *Stratigrafiya i paleogeografiya chetvertichnogo perioda Vostochnoi Evropy* (Quaternary Startigraphy and Paleogeography of Eastern Europe), Moscow: Inst. Geogr. Ross. Akad. Nauk, 1992, pp. 8–36.

Goretskii, G.I., *Allyuvial'naya letopis' velikogo Pra-Dnepra* (Alluvial Records of the Great Pra-Dnieper), Moscow: Nauka, 1970.

Goretskii, G.I., Types of Anthropogenic Overdeepenings (Several Regions of the Neman Basin as an Example), in *Problemy paleogeografii antropogena Belorussii* (Problems of the Anthropogene Paleogeography in Byelorussia), Minsk: Nauka i Tekhnika, 1973, pp. 95–127.

Goretskii, G.I., *Osobennosti paleopotamologii lednikovykh oblastei* (Peculiarities of Paleopotamology in the Glacial Areas), Minsk: Nauka i Tekhnika, 1980.

Gurskii, B.N., Provincial Differences in the Mineralogical Composition of Moraines of the Dnieper Horizon, *Dokl. Akad. Nauk BSSR,* 1971, vol. 15, no. 11, pp. 1024–1027.

Gurskii, B.N., Makhnach, N.A., Levkov, E.A., *et al.*, Stratigraphic Scheme of the Anthropogene Deposits of Byelorussia, in *Problemy izucheniya zemnoi kory Belorussii i sopredel'nykh territorii* (Problems of Investigations of the Earth's Crust in Byelorussia and Adjacent Territories: Reports of Byelorussian Geologists at the 27th Int. Geol. Congr., Moscow, 4–14 August, 1984), Minsk, 1986, pp. 30–37.

Janczyk-Kopikowa, Z., Flora Interglacjalu Mazowieckiego w Ferdynandowie, *Z. badan czwartorzedu w Polsce*, 1975, vol. 17, pp. 5–70.

Khursevich, G.K. and Loginova, L.P., Age of the Ancient Lacustrine Deposits of the Rechitsa Pridneprov'e and Paleogeographic Environment during Their Accumulation (According to Diatom Study), in *Pleistotsen Rechitskogo Pridneprov'ya Belorussii* (Pleistocene of the Rechitsa Pridneprov'e, Byelorussia), Minsk: Nauka i Tekhnika, 1986, pp. 76–142.

Komarovskii, M.E. and Yakubovskaya, T.V., Korchevo Interglacial Beds of the Minsk Upland, *Dokl. Akad. Nauk BSSR,* vol. 32, no. 3, pp. 256–259.

Kondratene, O.P. and San'ko, A.F., Mode of Occurence and Palynological Characteristic of the Interglacial Deposits in the Nizhninskii Rov Gorge, in *Problemy pleistotsena* (Problems of Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 101–124.

Kondratene, O.P., Khursevich, G.K., and Loginova, L.P., Biostratigraphic Substantiation of the Age of the Lacustrine Sequence Exposed in the Zhidini Section, in *Problemy pleistotsena* (Problems of Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 86–101.

Kriger, N.I., Lower Pleistocene Stratigraphy of the Glacial Regions of the Russian Plain, in *Nizhnii pleistotsen lednikovykh raionov Russkoi ravniny* (The Lower Pleistocene of the Glacial Regions of the Russian Plain), Moscow: Nauka, 1967, pp. 8–16.

Lepikash, I.A., Geological Map of the Quaternary Deposits of the USSR, Scale 1 : 1 000 000, *Tezi periodi konferntsii molodykh uchenykh Ukraini, geol.-geogr. sekts.* (Abstracts of the Periodical Conf. of the Young Ukrainian Scientists, Geol.-Geogr. Section), Kiev, 1936, pp. 3–7.

Lukashev, K.I. and Astapova, S.D., *Geokhimicheskie osobennosti morennogo litogeneza* (Geochemical Aspects of the Morainic Lithogenesis), Minsk: Nauka i Tekhnika, 1971.

Makhnach, N.A., *Etapy razvitiya rastitel'nosti Belorussii v antropogene* (Stages in Evolution of the Vegetation of Byelorussia During Anthropogene), Minsk: Nauka i Tekhnika, 1971.

Makhnach, N.A., *Palinologicheskaya kharakteristika drevneishikh antropogenovykh otlozhenii Belorussii* (Palynological Characteristic of the Most Ancient Anthropogenic Deposits in Byelorussia), Minsk: Nauka i Tekhnika, 1977, pp. 215–234.

Makhnach, N.A., Khursevich, G.K., Loginova, L.P., and Bogomolova, L.N., Recent Paleobotanic Investigations of the Ancient Lacustrine Pleistocene Deposits of the Krasnaya Dubrova Section, in *Neogenovye otlozheniya Belorussii* (The Neogene Deposits of Byelorussia), Minsk: Nauka i Tekhnika, 1982, pp. 37–53.

Makhnach, N.A. and Rylova, T.B., Stratigraphic Subdivision of the Ancient Lacustrine Pleistocene Deposits of the Rechitsa Pridneprov'e, in *Pleistotsen Rechitskogo Pridneprov'ya Belorussii* (Pleistocene of the Rechitsa Pridneprov'e, Byelorussia), Minsk: Nauka i Tekhnika, 1986, pp. 56–75.

Makhnach, N.A., Levkov, E.A., Gurskii, B.N., *et al.*, Stratigraphic Scheme of the Quaternary (Anthropogenic) Deposits of Byelorussia, *Dokl. Akad. Nauk BSSR,* 1970, vol. 14, no. 1, pp. 45–47.

Matveev, A.V., *Istoriya formirovaniya rel'efa Belorussii* (History of the Relief Formation in Byelorussia), Minsk: Nauka i Tekhnika, 1990.

Mojski, J.E., *Geology of Poland. vol. 1: Stratigraphy. Pt. 3b: Cenozoic–Quaternary,* Warszawa: Wyd. Geol., 1985.

Mojski, J.E., *Europa w plejstocenie: Ewolucja srodowiska przyrodniczego*, Warszawa, 1993.

Motuzko, A.N., Anthropogenic Rodents of Byelorussia and Adjacent Territories, in *Problemy pleistotsena* (Problems of the Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 173–188.

Nazarov, V.I., First Discovery of the Early Pleistocene Insects in the Novogrudskaya Highland, *Dokl. Akad. Nauk BSSR,* 1990, vol. 34, no. 1, pp. 75–78.

Nazarov, V.I., Study on Pleistocene Insects of Byelorussia, in *Problemy pleistotsena* (Problems of Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 168–199.

Neotektonika i poleznye iskopaemye Belorusskogo Poles'ya (Neotectonics and Mineral Resources of the Byelorussian Poles'e), Minsk: Nauka i Tekhnika, 1984.

Nikiforova, K.V., Range of Eopleistocene, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1987, no. 11, pp. 79–92.

Rylova, T.B., *Palinologicheskaya kharakteristika neogenovykh otlozhenii Belorusskogo Poneman'ya* (Palynological Characteristic of the Byelorussian Poneman'e), Minsk: Nauka i Tekhnika, 1980.

San'ko, A.F., Peculiarities of the Structure and Distribution of the Valdai Deposits of Byelorussia, in *Gealagichnyya i paleantalagichnyya dasledavanni kainazoyu Belarusi* (Geological and Paleontological Investigation of the Byelorussian Cenozoic), Minsk: Nauka i Tekhnika, 1989, pp. 59–64.

San'ko, A.F., Astapova, S.D., Rylova, T.B., *et al.*, Pleistocene Startigraphy and Paleogeography of the Kopyl'skaya Ridge, in *Paleogeografiya kainozoya Belorussii* (Cenozoic Paleogeography of Byelorussia), Minsk: Nauka i Tekhnika, 1989, pp. 53–66.

San'ko, A.F. and Motuzko, A.N., Geology, Flora, and Fauna of the Gralevo Section near Vitebsk, *Dokl. Akad. Nauk BSSR,* 1982, vol. 25, no. 6, pp. 540–543.

Tsapenko, M.M. and Makhnach, N.A., *Antropogenovye otlozheniya Belorussii* (The Anthropogene Deposits of Byelorussia), Minsk: Nauka i Tekhnika, 1959.

Tsapenko, M.M. and Makhnach, N.A., Stratigraphy of the Anthropogene Sequence in the Berezina Valley, in *Paleontologiya i stratigrafiya BSSR* (Paleontology and Biostratigraphy of the BSSR), Minsk: Nauka i Tekhnika, 1966, vol. 5, pp. 298–327.

Val'chik, M.A., Fedenya, V.M., and Krasavina, I.E., The Reference Section of the Murava–Lower Valdai Alluvial

Sequence in the Berezina River Valley, *Dokl. Akad. Nauk SSSR*, 1989, vol. 33, no. 7, pp. 649–651.

Vaznyachuk, L.M., Makhnach, N.A., Zus', M.Ya., and Kandratsene, O.P., New Data on the Lower Pleistocene of the Byelorussian Poneman'e and Position of the Korchev Interglacial Sequence among the Lower Pleistocene Deposits of Europe, in *Dasledovanni antrapagenu Belarusi* (Investigations of the Byelorussian Anthropogene), Minsk: Nauka i Tekhnika, 1978, pp. 63–81.

Velichkevich, F.Yu., *Pleistotsenovye flory lednikovykh oblastei Vostochno-Evropeiskoi ravniny* (Pleistocene Floras of Glacial Areas of the Eastern Russian Plain), Minsk: Nauka i Tekhnika, 1982.

Velichkevich, F.Yu., Pliocene Relicts in the Pleistocene Floras of Byelorussia, *Proc. Symp. "Paleofloristic and Paleoclimatic Changes in the Cretaceous and Tertiary", 1989*, Prague, 1990, pp. 281–283.

Velichkevich, F.Yu. and Rylova, T.B., New Discovery of the Early Pleistocene Flora in Southeastern Byelorussia, *Dokl. Akad. Nauk BSSR*, 1988, vol. 32, no. 11, pp. 1014–1017.

Velichkevich, F.Yu., Nazarov, V.I., Rylova, T.B., *et al.*, Present Conception of the Pleistocene Stratigraphy in Belarus, in *Byulleten' regional'noi mezhvedomstvennoi stratigraficheskoi komissii po Tsentru i Yugu Russkoi platformy* (Bulletin of the Regional Interdepartmental Stratigraphic Commission on the Central and Southern Russian Plain), Moscow, 1992, vol. 1, pp. 149–153.

Velichkevich, F.Yu., Rylova, T.B., San'ko, A.F., and Fedenya, V.M., *Berezovskii stratoraion pleistotsena Belorussii* (The Bereza Stratotypical Region of the Byelorussian Pleistocene), Minsk: Nauka i Tekhnika, 1993.

Voznyachuk, L.N., Limit of the Last Glaciation in Byelorussia, *Uchen. Zap. Belorus. Gos. Univ., Ser. Geol.*, 1956, vol. 28, pp. 170–196.

Voznyachuk, L.N., The Last Interglacial Deposits in Byelorussia, in *Materialy po antropogenu Belorussii* (Materials on the Anthropogene in Byelorussia), Minsk: Akad. Nauk BSSR, 1961, pp. 159–217.

Voznyachuk, L.N., Main Stratigraphic Subdivisions of the Quaternary Deposits, in *Materialy po stratigrafii Belorussii* (Materials on the Stratigraphy of Byelorussia), Minsk: Nauka i Tekhnika, 1981, pp. 137–151.

Voznyachuk, L.N., Problems of the Glaciopleistocene of the East-European Plain, in *Problemy pleistotsena* (The Problems of Pleistocene), Minsk: Nauka i Tekhnika, 1985, pp. 8–55.

Voznyachuk, L.N., Gripinskii, N.M., and Puzanov, L.T., Stratigraphy, Quaternary System, in *Geologiya SSSR* (Geology of the USSR), Moscow: Nedra, 1971, vol. 3, pp. 231–290.

Voznyachuk, L.N. and Puzanov, L.T., History of the Geologic Evolution. Quaternary Period, in *Geologiya SSSR* (Geology of the USSR), Moscow: Nedra, 1971, vol. 3, pp. 416–430.

Voznyachuk, L.N., Makhnach, N.A., Motuzko, A.N., *et al.*, The Lower Pleistocene Deposits in the Village of Korchevo, the Novogrudskaya Highland, Byelorussia, and Their Stratigraphic and Paleogeographic Significance, *Dokl. Akad. Nauk BSSR*, 1977, vol. 21, no. 11, pp. 1025–1028.

Voznyachuk, L.N. and Puzanov, L.T., Brief Characteristics of Main Quaternary Stratigraphic Horizons in Byelorussia Based on New Data, in *Materialy 4 konferentsii po geologii Belorussii i Pribaltiki* (Proc. 4th Conf. on Geology of Byelorussia and Baltic Countries), Minsk: Nauka i Tekhnika, 1966, pp. 190–198.

Yakubovskaya, T.V., *Paleogeografiya likhvinskogo mezhledenikov'ya Grodnenskogo Poneman'ya* (Paleogeography of the Likhvin Interglaciation in Poneman'e near Grodno), Minsk: Nauka i Tekhnika, 1976.

Yakubovskaya, T.V., *Ocherk neogena i antropogena Poneman'ya* (Synopsis of the Neogene and Anthropogene in Poneman'e), Minsk: Nauka i Tekhnika, 1984.

Yakubovskaya, T.V., New *Decadon* Species from the Early Quaternary Flora of the Southern Byelorussia, *Dokl. Akad. Nauk BSSR*, 1989, vol. 33, no. 11, pp. 1023–1031.

Yakubovskaya, T.V., Khursevich, G.K., and Rylova, T.B., New Data on the Stratotype of the Belovezh'e Interglaciation, *Dokl. Akad. Nauk BSSR*, 1991, vol. 35, no. 3, pp. 262–265.

Yakubovskaya, T.V. and Nazarov, V.I., Stratigraphic Scheme of Eopleistocene Deposits of Byelorussia, *Dokl. Akad. Nauk Belarus*, 1993, vol. 37, no. 4, pp. 100–104.

Yakubovskaya, T.V. and Rylova, T.B., The Late Cenozoic Floras of the Region with the Neogene Karst Manifestation near Bereza, in *Flora i fauna kainozoya Belorussii* (Cenozoic Flora and Fauna of Byelorussia), Minsk: Nauka i Tekhnika, 1992, pp. 76–94.

Zinova, R.A., Rylova, T.B., Dromashko, S.G., *et al.*, *Pliotsen Rechitskogo Pridneprov'ya Belorussii* (Pliocene of the Rechitsa Pridneprov'e, Byelorussia), Minsk: Nauka i Tekhnika, 1987.

Zus', M.E., *Novogrudskaya vozvyshennost': Geologicheskoe stroenie, glyatsiotektonika, etapy formirovaniya* (The Novogrudskaya Highland. Geology, Glacial Tectonics, and Stages of Formation), Minsk: Nauka i Tekhnika, 1991.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 606–612. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 88–95.
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Jurassic–Early Cretaceous Landscapes with the Hot Humid Climate in the Northern Arabian Plate

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Abstract—During major regressions in the Early–Middle Jurassic to Early Cretaceous, the northern Arabian plate, which was traditionally referred to the province with a hot arid or variably humid climate, featured oases with hot humid climates as is evident from lithologic and palynologic data. According to the palinspastic reconstructions, these areas of hot humid land were located at that time in the near-equatorial regions of the earth. Therefore, their appearance suggests that the ancient equatorial belt was eventually formed in the Late Cretaceous from separate humid oases, which existed along the northern periphery of the African–Arabian land as early as the Jurassic–Early Cretaceous.

Key words: *Syria, Jurassic, Lower Cretaceous, hot humid paleoclimate.*

When interpreting paleoclimatic evolution, researchers believe that in the Late Jurassic–Early Cretaceous, the northern African–Arabian platform represented a land with hot arid or semiarid climatic environments (Vakhrameev, 1990; Ronov and Balukhovskii, 1981; Ushakov and Yasamanov, 1984). During the Early–Middle Jurassic, a time of global transgression, a humid and variably humid tropical climate is thought to be characteristic of the Arabian plate (Ushakov and Yasamanov, 1984), or at least its northern part (Vakhrameev, 1990). Some authors (Parrish *et al.*, 1982) argued that humid landscapes on the Arabian land existed not only at the beginning of the Jurassic, but in the terminal Jurassic as well.

My research in Syria from 1989–1991 and published data on the adjacent territories of Israel, Lebanon, and Iraq suggest that during some periods of the Jurassic, the northwestern Arabian land was the area of the formation of specific rock parageneses, which explains the extended areas there with hot (equatorial–tropical) climates also recorded by palynological data.

During the Early–Middle Mesozoic, the northern margin of the Arabian plate (except areas of ancient land adjacent to the Arabian-Nubian shield) was covered by shallow marine basins of the southern Mesozoic Tethys. In these basins, mainly carbonate, less commonly sulfate, and sometimes salt-bearing deposits accumulated. The sedimentation patterns were different during major regressions, when the land areas considerably widened, and terrigenous deposits (terrestrial and coastal-marine) became dominant. Two major stages were defined and traced in the Jurassic–Lower Cretaceous sequences of Syria (Fig. 1): in the Palmirides (I), Anti-Lebanon (II), Coastal Ranges (III), and Kurd-Dagh (IV). The first of them is dated as the Early Jurassic (pre-Bathonian), and the second one is the Early Cretaceous in age, spanning from the Neocomian to Early Albian.

The stratigraphy and correlation of the Jurassic–Early Cretaceous regressive units in Syria, shown in Fig. 2, somewhat differ from those in an earlier scheme (*Geologiya ...*, 1969). I introduced some changes based on more recent data obtained by Syrian geologists mapping (scale 1 : 50 000) the Coastal Ranges territory (Adjamian and Al-Bakka, 1984; Adjamian and Jamal, 1983; Yousef, 1979; and others), as well as on the materials of the complex lithologic-facial and stratigraphic

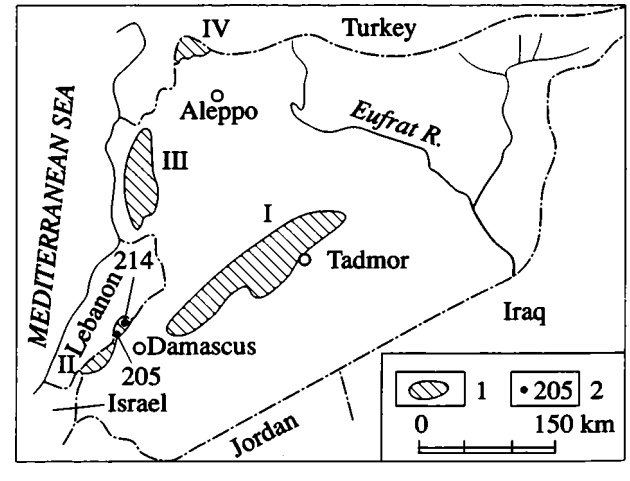

Fig. 1. Location of studied areas in Syria.
1. areas of investigations: (I) Palmirides, (II) Anti-Lebanon, (III) Coastal Ranges, (IV) Kurd-Dagh; 2. Arabic numerals show the location of Lower Cretaceous humid sections given in Fig. 2.

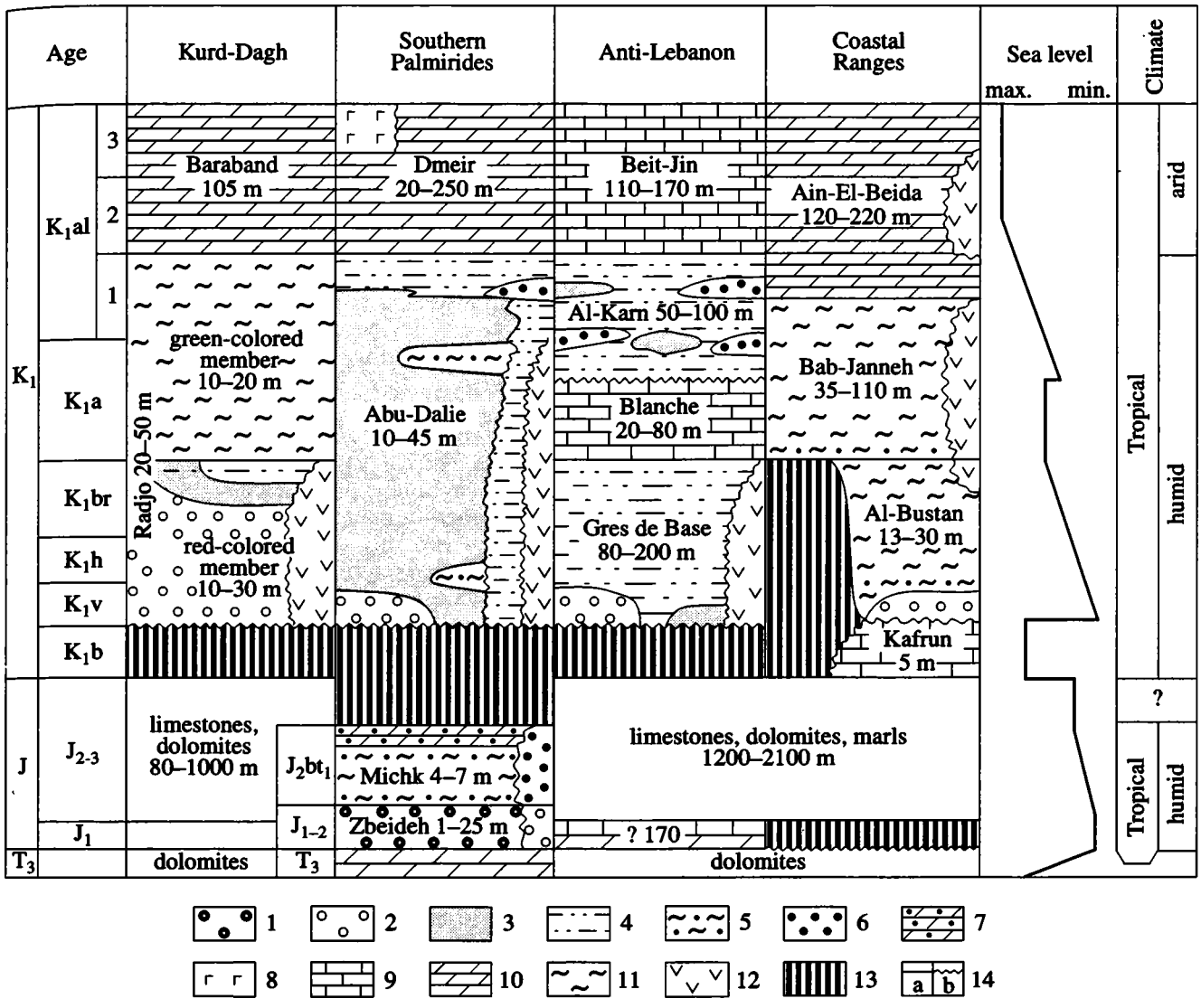

Fig. 2. Lithology and correlation of sections of the Early–Middle Jurassic and Early Cretaceous regressive stage in Syria.
Continental deposits: 1. clastic bauxites, allites, and kaolinic clays with inclusions of clastic (karstic) iron ores; 2. clastic iron ores with intercalations and lenses of kaolinic clays (karstic and coastal plane); 3. quartzose sandstones, siltstones, kaolinic clays (deposits of coastal planes). Coastal-marine deposits: 4. quartzose sandstones, siltstones, and clays (kaolinic and, locally, smectitic), often calcareous, with marl and limestone interbeds; 5. clays calcareous (often dolomitic and sandy), illitic, locally smectitic, sometimes with lenses of oolitic iron ores; 6. oolitic iron ores; 7. limestones and dolomitic limestones, commonly sandy, with inclusions of dolomites; 8. gypsum, anhydrites, clays with gypsum. Marine deposits: 9. limestones with marl and clay interbeds; 10. dolomites, dolomitic limestones with limestone and marl inclusions and clay interbeds; 11. dolomitic marls and dolomitic clays (ferrilithic, smectitic) with inclusions of dolomite and limestone. Volcanogenic-sedimentary rocks: 12. basalts or their tuffs; 13. hiatuses; 14. boundaries: a, conformable, b, unconformable (hiatus).

research conducted by the Soviet-Syrian expedition in 1989–1991. The results of these latter investigations were only partly published (Kotova, 1990; Tsekhovskii *et al.*, 1993, 1994a, 1994b).

THE EARLY–MIDDLE JURASSIC REGRESSIVE STAGE

In the northern Arabian plate, the Mesozoic era started with the accumulation of the Triassic marine, mostly carbonate formations, and the wide development of salt- and, gypsum-bearing and dolomitic rocks (Bebeshev *et al.*, 1990; Hirsch, 1984; and others), which were characteristic of the arid climatic setting. The terminal Triassic–early Middle Jurassic was marked in Syria by a regression that was accompanied by breaks in sedimentation.

On the ancient land, the terrestrial deposits of this age (the Zbeideh Formation) were established and studied (Tsekhovskii *et al.*, 1993) only in the southern Palmirides (Fig. 2). These 25-m-thick deposits fill the

karst cavities and predominantly consist of red-colored deluvial–proluvial products derived from the lateritic weathering crust (kaoline clays, boehmite bauxites and allites, and clastic goethite-hematite iron ores). Present in the deposits are ferrilithic (ferruginous-kaolinitic) buried soils.

In the southern Palmirides, the overlying transgressive rhythm of carbonate rocks starts with the lower Bathonian clayey-carbonate coastal-marine deposits of the Michk Formation (up to 7 m thick), which contain aggregates of oolitic goethite-hematite iron ores and kaoline clays.

The above-noted parageneses of the Lower–Middle Jurassic sedimentary rocks serve as indicators of the hot humid paleoclimate (Strakhov, 1960; Sinitsyn, 1976) on the ancient land where lateritic processes prevailed. It should be noted that among the considered Early–Middle Jurassic and similar (described below) Neocomian–lower Albian sedimentary parageneses (Fig. 2), there are interbeds of marine ferrilithic–dolomitic rocks and terrestrial alunites, whose presence is atypical for the humid environments. The causes of their formation will be discussed below.

In other areas of Syria, the deposits of the considered regressive stage were not recorded. Presumably, marine limestone and dolomitic deposits at the base of the Middle–Upper Jurassic sequences in the Anti-Lebanon and Central Palmirides that lack guide fossils can be referred to the Lower Jurassic (*Geologiya* ..., 1969).

Outside Syria, hot tropical climatic environments existed in the Early Jurassic on the ancient land in the current territory of Israel. The considered regressive stage was most prominent there during the Hettangian–Sinemurian (Hirsch, 1984, 1990); however, locally in the Negev, Eilat and other areas of south-southeastern Israel, it also encompassed the Latest Triassic (Norian). This period is marked by a hiatus, lateritization of underlying rocks, and, locally, by the formation of reworked products of lateritic weathering crusts in karst cavities, which are observed in the Mishor Formation. The latter consists of typical terrestrial deposits (bemite bauxites, iron-ores, and kaoline clays), with the horizons of buried soils of the lateritic type. These buried soils were most thoroughly described in the Makhtesh Ramon locality (Goldbery, 1979, 1982).

The presence of dolomite–gypsum horizons within some Pliensbachian–Aalenian predominantly carbonate sequences of Israel suggests the existence there of a transitional area of dryer landscapes with the semiarid or arid climate typical of the African–Arabian land at that time (Vakhrameev, 1990; Ushakov and Yasamanov, 1984).

The above-listed data on lateritic weathering and the formation of bauxite-bearing, coaliferous, and iron ore deposits in the territories of Israel and Syria serves as the basis for distinguishing a land area there with a tropical humid climate that represented an oasis against the background of more arid landscapes in the adjacent regions of Africa and Arabia. This oasis also comprised the western part of Iraq, where the considered time was characterized by iron ore formation (Petranek and Jassim, 1980). It is believed that the lateritic weathering crust of the adjacent land served as the source of the ore matter, and that the most favorable environments for ore formation resulted from the replacement of the regressive regime with a transgressive one.

From the second half of the Bathonian to the end of the Jurassic (locally, probably, up to the terminal Berriasian), transgression in the marginal seas of Syria and Israel promoted the accumulation predominantly of limestones, sometimes with marly and clayey members (*Geologiya* ..., 1969; Hirsch, 1984, 1990). These carbonate sequences lack rock indicators of the arid climate—sedimentary salts, gypsum, and dolomite. Therefore, one can suggest the existence in this region of humid environments during that time interval, except in the northernmost areas, where they probably became arid. However, this conclusion on the Middle–Late Jurassic climate requires verification and more reliable substantiation.

THE EARLY CRETACEOUS REGRESSIVE STAGE

At the beginning of the Cretaceous (Valanginian to early Albian), the Middle–Late Jurassic transgression in Syria was followed by the second regressive stage (Fig. 2). The continental terrigenous deposits, with subordinate carbonate-terrigenous coastal-marine sediments, accumulated at that time mainly in the southeastern and northern areas of the country. They compose the Abu Dalie and Radjo formations in the Palmirides and Kurd-Dagh, respectively. In the northern areas of Syria, the coastal-marine and marine deposits prevail. In Anti-Lebanon, southwestern Syria (Fig. 3), these are predominantly coastal-marine calcareous-terrigenous deposits of the Gres de Base and Al-Karn formations (locally, with lenses of terrigenous terrestrial rocks). Marine carbonate deposits of the Blanche Formation are also developed there. Marine clayey-carbonate and carbonate rocks are widespread throughout the Coastal Range area in the northwest part of the country, where they are present in the Bab-Janeh and Al-Bustan formations. The exception is in the southern part of this region, where the basal layers of the latter formation incorporate lenses and members of coastal-marine and terrestrial carbonate-terrigenous rocks.

In the Anti-Lebanon region, the considered regressive stage was complicated by local transgression which resulted in the accumulation of the carbonate Blanche Formation. This transgression was pronounced in the Lebanon and Israel territories, whereas no noticeable traces were observed in the Lower Cretaceous sequences of Syria.

It should be emphasized that terrestrial and coastal-marine terrigenous deposits under consideration are universally composed of reworked products of the ferruginous-kaolinic humid weathering crusts. They are represented by quartzose sands or sandstones with a ferruginous-kaolinic matrix, kaolin clays, and clastic pebble-gravel iron ores of the goethite-hematite composition. The maximum thickness of iron-ore horizons (up to 30 m) is observed within the Radjo Formation, which fills the karst hollows in the Kurd-Dagh area. The coastal-marine sequences incorporate lenses and beds of oolitic iron ores of the siderite–goethite–leptochlorite composition. They are most commonly located within the Al-Karn Formation of Anti-Lebanon (Fig. 3), where in some sequences, they are 6.5 m thick. Accumulations of iron ores form horizons 12–25 thick, in which ores alternate with ore-free terrigenous rocks. In the older Gres de Base Formation of Anti-Lebanon, oolitic iron ores give way to sandstones and siltstones with a ferruginous matrix, as well as to clastic terrestrial iron ores. These latter are observed in basal layers of the Lower Cretaceous sequence near the village of North Bloudan.

The Lower Cretaceous terrestrial deposits of Syria are also characterized by the presence of ferrilithic-fossil-soil horizons, which are locally crowned by cuirasses.

The analysis of the above-mentioned data on the composition of the Lower Cretaceous terrigenous deposits of Syria allows the suggestion that they accumulated in hot humid environments under the prevalence of the ferrilithic weathering processes. This conclusion on the ancient climate features is supported by palynological data (Kotova, 1990).

The author has defined and studied six palynological complexes from the Lower Cretaceous sequences in the Vadi-Al-Karn and Ididet-Yabous areas in Anti-Lebanon. The complexes are mainly confined to three formations, which accumulated during the considered regressive stage: the upper Gres de Base Formation (palynological complexes I and II), Blanche Formation (III), and Al-Karn Formation (IV and V), which are dated as the Neocomian–early Albian based on macro- and microfaunal data. The spectra in most of the complexes (I to V) show constantly high concentrations of fern spores and low contents of the *Classopollis* pollen, thus suggesting the humid tropical climate. In the top layers of the Al-Karn Formation and overlaying Beit-Jin Formation, which correspond to the transgressive stage, the palynological complex VI shows an abrupt reduction in fern spore content and the prevalence of *Classopollis* pollen, which indicates arid climatic environments. This conclusion is confirmed by the wide development of marine dolomitic rocks locally with gypsum beds in Syria (Fig. 2), which accumulated during the middle–late Albian (sequences in the Coastal Ranges, Palmirides, and Kurd-Dagh areas).

Similar terrigenous deposits accumulated during the considered regressive stage in the adjacent territories of the northwestern Arabian Peninsula (Hirsch, 1984, 1990). In Israel, they are sandy-clayey and sandy rocks of the Berriasian–Aptian marine Helez Formation and Berriasian–Early Albian terrestrial Hatiza Formation. These deposits are represented by sufficiently mature products, which were derived from lateritic and kaolinic weathering crusts (quartz and kaolinic clays), and constitute the essential part of the Nubian Sandstones.

In Lebanon, there are relics of this Lower Cretaceous alluvium, which is represented by ferruginous lateritic weathering crusts on the Upper Jurassic basalts and products of their redeposition (Petranek and Jassim, 1980). These latter are composed of clastic iron ores filling the karst cavities in Jurassic carbonate rocks. At the base of the Aptian–Albian Nubian Sandstones in Palestine, marine oolitic iron ores overlying with a hiatus the Jurassic limestones are observed as well. These ores are also recorded at the base of the Lower Cretaceous sequence in southern Turkey (Petranek and Jassim, 1980). In some islands in the marginal part of the Tethys along the Arabian plate periphery, karst bauxites (the Menderas massif; *Istoriya* ..., 1987) accumulated during the Aptian in addition to the above-mentioned ores. In the Taurus-Zagros autochthonous region, the bauxite accumulation also continued in the later, Albian–Cenomanian period (Hirsch, 1984).

In the inner Arabian plate, the formation of the Aptian-Albian lateritic weathering crusts was recorded in the Az-Zabirah locality, northeastern Saudi Arabia (Bardossy and Allva, 1990).

Thus, the analyzed data on sedimentation during the considered regressive stages of the Early–Middle Jurassic and Early Cretaceous suggest the wide development in the northwestern Arabian plate of continental hot humid landscapes. The humid tropical climate favored the formation of kaolinic and lateritic weathering crusts and products of their reworking (quartzose sands, iron ores, and bauxites). In some swampy land areas of Israel, coaliferous and coal-bearing deposits accumulated. The termination of the Early–Middle Jurassic regressive stage in Israel also shows some episodes with arid climatic environments, which were marked by the accumulation of dolomitic and dolomtic-gypsiferous deposits.

Earlier, it was noted that deposits typical of the humid environments of the Jurassic and Cretaceous regressive stages in Syria incorporate unusual rock parageneses. In terrestrial deposits of the Palmirides, they are represented by alunite inclusions that form small aggregates, or lenses in sandstones, and matrix in clastic rocks. In the sections located in the vicinity of the Mazar Range of the northern Palmirides, the thickness of Lower Cretaceous sandstones with the monomineral alunite matrix in the Abu-Dabie Formation is 40 m. The Jurassic and Cretaceous Michk, Abu-Dalie, Al-Bustan, and Bab-Janneh Formations, and the green-

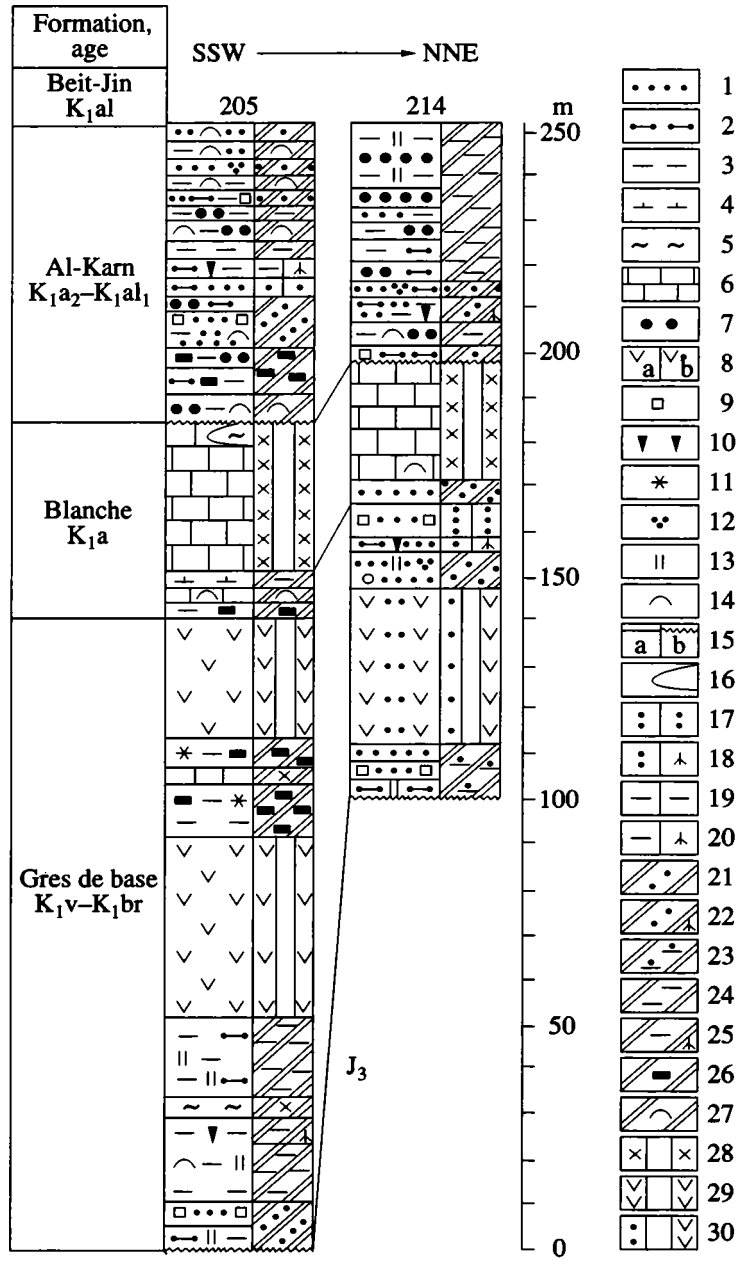

Fig. 3. Lithology and facies of deposits accumulated under the hot humid paleoclimate in the Anti-Lebanon (205—Vadi-Al-Karn, 214—Northern Bludan).

Rocks (1–8): 1. sandstones; 2. siltstones; 3. clays; 4. calcareous clays; 5. marls; 6. limestones; 7. oolitic iron ores; 8. volcanogenic rocks; a, basaltic lavas, b, tuff sandstones and tuff claystones. Autigenic and secondary minerals in a form of aggregates and concretions, or composing matrix in sandstones and siltstones (9–12): 9. goethite; 10. soil spots and aggregates of goethite and hematite; 11. gypsum; 12. glauconite; 13. red-colored rocks; 14. abundant macrofauna; 15. boundaries: a, conformable, b, unconformable (hiatus); 16. thin (out of scale) lenses or intercalations. Facies (17–29). *Continental* (17–20): 17. silty-sandy river bed alluvium; 18. sandy-silty alluvium revorked by ancient soil formation; 19. clayey and silty-clayey flood plain alluvium; 20. clayey and silty-clayey flood plain alluvium reworked by ancient soil formation. *Coastal-marine* (21–27): 21. sandy-silty (locally ferruginous) and clayey deposits of coastal shoals with high-energy hydrodynamics; 22. sandy-silty, locally clayey deposits of coastal shoals with high-energy hydrodynamics reworked by ancient soil formation; 23. sandy-clayey deposits of underwater deltas; 24. clayey, locally feruginous deposits of coastal shoals with low-energy hydrodynamics; 25. clayey deposits of coastal shoals with low-energy hydrodynamics reworked by ancient soil formation; 26. coaly-clayey, locally ferruginous of swampy areas of coastal shoals; 27. organogenic-clayey-calcareous, locally ferruginous deposits of organogenic build-ups or products of their redeposition in the coastal shoals. *Open-marine*: 28. calcareous deposits of distant offshore areas with low-energy hydrodynamics. *Volcanogenic and volcanogenic-sedimentary* (29 and 30): 29. basaltic and tuff lavas of underwater volcanic edificies and adjacent areas; 30. tuff-sandy and tuff-clayey deposits.

colored unit of the Radjo Formation show the presence of sedimentary ferrilithic rock members, which are a few to several dozens of meters thick. As it was shown in special studies (Tsekhovskii *et al.*, 1994), their origin was probably related to hydrothermal activity. In the ancient land, the latter favored alunite accumulation in the form of aggregates and lenses, and also alunitization of kaolin in the sandstone and siltstone matrix. In the areas of discharge of Jurassic and Cretaceous underwater hydrothermal springs, the chemical composition of sea water also changed, which promoted the accumulation of ferrilith-dolomite deposits in the humid environments. These deposits distinctly stand out against the background of rocks typical of that time (quartzose sandstones, siltstones, kaolinic clays, marls, and limestones).

With regard to palinspastic reconstructions (Smith *et al.*, 1981; Funnel, 1988), the considered areas may be thought of as having occurred in the near-tropical part of Gondwana.

Almost all researchers point to the existence, at least since the Late Cretaceous, of the equatorial humid climatic belt within low latitudes of the earth, which gave way to the northern and southern tropical belts in higher latitudes. When considering paleogeography, some authors extrapolate these patterns on older Mesozoic epochs and show them in the paleogeographic schemes compiled, for instance, for the Late Jurassic, Neocomian, and Albian (Ronov and Balukhovskii, 1981), or the Late Triassic and Late Jurassic (Ushakov and Yasamanov, 1984), introducing only some changes into the contours of Late Cretaceous climatic belts.

Other geologists reasonably believe that during the first half of the Mesozoic, the paleoclimate in low latitudes of the Gondwanaland distinctly differed from the modern one in the absence of the permanent humid equatorial belt and existence of the single belt with the hot arid climate. The latter included the northern and southern tropical belts, where separate humid oases appeared during certain periods. Such climatic environments are exemplified by data on the Late Jurassic and Early Cretaceous (Vakhrameev, 1990), as well as by Aptian and Albian (Chumakov *et al.*, 1995) paleogeography. Other authors (Parrish *et al.*, 1982) argue that, unlike now, older Mesozoic humid climatic belts (for instance, in the Early Triassic and Early Jurassic) bounded maritime landscapes in the northeastern periphery of the African–Arabian land, stretching submeridionally in lower paleolatitudes. The latitudinal equatorial humid belt in Gondwanaland appeared only in separate epochs of global climate humidization during the first half of the Mesozoic, for instance, in the Middle or Late Jurassic (Vakhrameev, 1990; Parrish *et al.*, 1982, respectively). Recent publications (Chumakov *et al.*, 1995) show that the onset of the humid equatorial belt in lower paleolatitudes proceeded at the beginning of the Late Cretaceous, and that it replaced the hot arid landscapes of the first half of the Cretaceous, when the first isolated areas with humid climates locally appeared. The data considered in the present paper suggest that environments of hot humid landscapes (oases) existed in the northeastern margin of the African–Arabian land even earlier, i.e., in the Early Jurassic and Early Cretaceous, coinciding in time with the epochs of global regressions. Later, in the Albian, areas of these oases widened, covering the inner parts of the Gondwanian continent forming in the Cretaceous the above-mentioned humid equatorial belt (Tsekhovskii *et al.*, 1995).

In conclusion, it should be stressed that the existence of extended areas with hot humid peneplane landscapes in the ancient Arabian land at the beginning of the Early Jurassic and Early Cretaceous allows them to be considered as promising areas with respect to mineral resources, such as terrestrial and coastal-marine iron ores, glass sands, fire clays, bauxites, and others related to the lateritic or kaolinic eluvial deposits and products of their redeposition.

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REFERENCES

Adjamian, J. and Al-Bakka, F.F., *Geological Map of Syria (Scale 1 : 50 000): Misiaf Sheet, Syria Arab Republic*, Damascus, 1984.

Adjamian, J. and Jamal, N.E., *Geological Map of Syria (Scale 1 : 50 000): Qalaat Al Housen Sheet, Syria Arab Republic*, Damascus, 1983.

Bardossy, G. and Allva, G.I., *Lateritic Bauxites*, Budapest: Academia Kiado, 1990.

Bebeshev, I.I., Dzhalilov, Yu.M., Yudin, G.T., *et al.*, Evolution of the Northern Arabian Platform in the Triassic (with Syria as an Example), *Litol. Polezn. Iskop.*, 1990, no. 5, pp. 66–79.

Chumakov, N.M., Zharkov, M.A., Herman, A.B., *et al.*, Climatic Belts in the Mid-Cretaceous Time, *Stratigr. Geol. Korrelyatsiya*, 1995, no. 3, pp. 89–99.

Funnel, B.M., Global and European Cretaceous Shorelines, Stage by Stage, in *Cretaceous Resources, Events, and Rhythms*, Dordrecht: Kluwer, 1988, pp. 221–235.

Geologiya i poleznye iskopaemye zarubezhnykh stran. Siriya (Geology and Mineral Resources of Foreign Countries: Syria), Leningrad: Nedra, 1969.

Goldbery, R., Early Diagenetic Nonhydrothermal Na-Alunite in Jurassic Flint Clays, Makhtesh Ramon, Israel, *Bull. Geol. Soc. Am.*, 1978, vol. 89, no. 5, pp. 687–698.

Goldbery, R., Sedimentology of the Lower Cretcaeous Flint Clays-Bearing Mishor Formation, Makhtesh Ramon, Israel, *Sedimentology*, 1979, vol. 26, no. 2, pp. 229–251.

Hirsch, F., The Arabian Sub-Plate during the Mesozoic: The Geological Evolution of the Eastern Mediterranean, *Geol. Soc. Spec. Publ.*, 1984, no.17, pp. 217–222.

Hirsch, F., Apercu de l'histore pahanerozoique d'Israel, *Afr. Earth Sci.*, 1990, vol. 11, nos. 1/2, pp. 177–196.

Istoriya okeana Tetis (Evolution of the Tethys Ocean), Moscow: Inst. Okeanologii, 1987.

Kotova, I.Z., Lower Cretaceous Palynocomplexes of Siria, in *Paleofloristika i stratigrafiya fanerozoya* (Paleofloral Record and Stratigraphy of the Phanerozoic), Moscow: Nauka, 1990, pp. 85–101.

Parrish, J.T., Ziegler, A.M., and Scotes, C.R., Rainfall Patterns and the Distribution of Coals and Evaporites in the Mesozoic and Cenozoic, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1982, vol. 40, pp. 67–101.

Petranek, J. and Jassim, S.Z., Iron Ore Deposition within the Arabian Peninsula in Time and Space, *J. Geol. Soc. Iraq.*, 1980, vol. 13, no. 1, pp. 169–175.

Ronov, A.B. and Balukhovskii, A.N., Climatic Zonation of Continents and General Tendency in Climatic Changes during the Late Mesozoic and Cenozoic, *Litol. Polezn. Iskop.*, 1984, no. 5, pp. 118–135.

Sinitsyn, V.M., *Klimat laterit-boksita* (Climate of the Laterite-Bauxite), Leningrad: Nedra, 1976.

Strakhov, N.M., *Osnovy teorii litogeneza* (Fundamentals of Lithogenesis.), Moscow: Akad. Nauk SSSR, 1960, vol. 1; 1961, vol. 2; 1962, vol. 3.

Tsekhovskii, Yu.G., Bogatyrev, B.A., and Jabbur, P., Triassic–Jurassic Bauxites of Syria, *Litol. Polezn. Iskop.*, 1993, no. 4, pp. 34–50.

Tsekhovskii, Yu.G., Murav'ev, V.I., and Jabbur, P., Hydrothermal-Sedimentary Lithogenesis in the Arabian Plate (in Jurassic–Cretaceous Continental Landscapes). Article 1, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1994a, no. 2, pp. 33–40.

Tsekhovskii, Yu.G., Murav'ev, V.I., and Jabbur, P., Hydrothermal-Sedimentary Lithogenesis in the Arabian Plate (in Jurassic–Cretaceous Continental Landscapes). Article 2, *Izv. Vyssh. Uchebn. Zaved., Geol. Razved.*, 1994b, no. 3, pp. 50–59.

Tsekhovskii, Yu.G., Shchipakina, I.G., and Khramtsev, I.N., Lateritic Eluvium and Its Redeposition Products as Indicators of Aptian–Turonian Climate, *Stratigr. Geol. Korrelatsiya*, 1995, vol. 3, no. 3, pp. 89–99.

Ushakov, S.A. and Yasamanov, N.A., *Dreif materikov i klimaty Zemli* (Continental Drift and Earth Climates), Moscow: Mysl', 1984.

Vakhrameev, V.A., *Izbrannye trudy. Paleofloristika, fitogeografiya i klimaty mezozoya* (Paleoflora, Phytogeography, and Climates of the Mesozoic), Moscow: Nauka, 1990.

Yousef, S., *Geological Map of Syria (Scale 1 : 50 000): Sheet Haffeh, Syrian Arb Republic,* Damascus, 1979.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 613–615. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 96–98.
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BRIEF COMMUNICATIONS

First Discovery of Conodonts from Upper Triassic Deposits of Kotel'nyi Island

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Key words: *Kotel'nyi Island, Triassic, Carnian, Norian, conodonts.*

INTRODUCTION

Data on Triassic conodonts from North Siberia are quite unsystematic. These fossils show the highest taxonomic diversity in the Lower Triassic strata, especially in bituminous limestones of the Chekan Formation (Dagys, 1982, 1984a, 1984b, 1986, 1991). In the Middle Triassic deposits, conodonts are considerably less abundant. Their occurrences are surely known in the Anisian and Ladinian beds of the eastern Taimyr (Dagys *et al.*, 1979) and northeastern Russia, in the Arga-Tas Range and Omolon massif (Terekhov and Dylevskii, 1988; Dagys, 1991). Recently it was believed that Upper Triassic boreal sections of North Siberia are barren of conodonts (Dagys *et al.*, 1989), and I was of the same opinion. Nevertheless recent discoveries of conodonts from Upper Triassic beds of Kotel'nyi Island change the former concept on their stratigraphic range in the region under consideration.

DISTRIBUTION OF CONODONTS THROUGH THE SECTION

The composite Triassic section of Kotel'nyi Island (Novosibirsk structural-facial zone) is described by Egorov *et al.* (1987). Its Upper Triassic beds are distinct due to several features: they are monotonous and shaly in composition, show an elevated content of carbonate components and limited thickness (500 m), and enclose abundant organic remains, such as bivalves, ammonoids, nautiloids, brachiopods, foraminifers, and ostracodes. Conodonts were first discovered near the Stantsiya Lagoon and in the Tikhaya River basin (Fig. 1).

The lower horizons of the Carnian Stage (Exposure 195, Member 16, see Fig. 1a) occur in the north of the island, 2 km west of the Stantsiya locality. The member displays the 10-cm-thick alternation of black shaly and light-gray massive clays. Throughout its section (20 m in total), the member encloses rare lenses, 1 m long and 0.15 m thick, of dark-gray bituminous limestone and brown clayey dolomite. Two levels of the unit (2.9 and 14 m above the base) contain abundant *Halobia* sp.; two others (16 and 20 m above the base) yielded *Pleuromya* cf. *musculoides* Shloth., *H.* cf. *korkodonica* (Polub.), and *Planirhynchia yakutica* Dagys. *Discohyllites* sp. was distinguished at the level of 13 m above the base. In addition, one limestone lens, which is located at 18 m above the member base, yielded few conodont remains, among them *Neogondolella foliata*

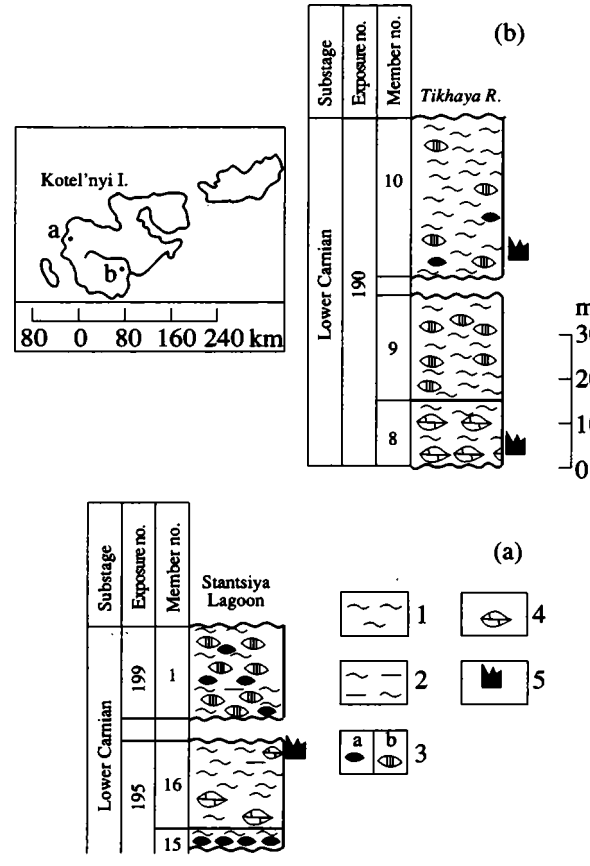

Fig. 1. Lithostratigraphic columns for Triassic deposits in Kotel'nyi Island (after Egorov *et al.*, 1987) and their geographic localities, (a) Stantsiya Lagoon and (b) Tikhaya River basin: (1) clay; (2) argillaceous clay; (3) concretions: phosphorite (a) and siderite (b); (4) limestone lenses; (5) conodont localities.

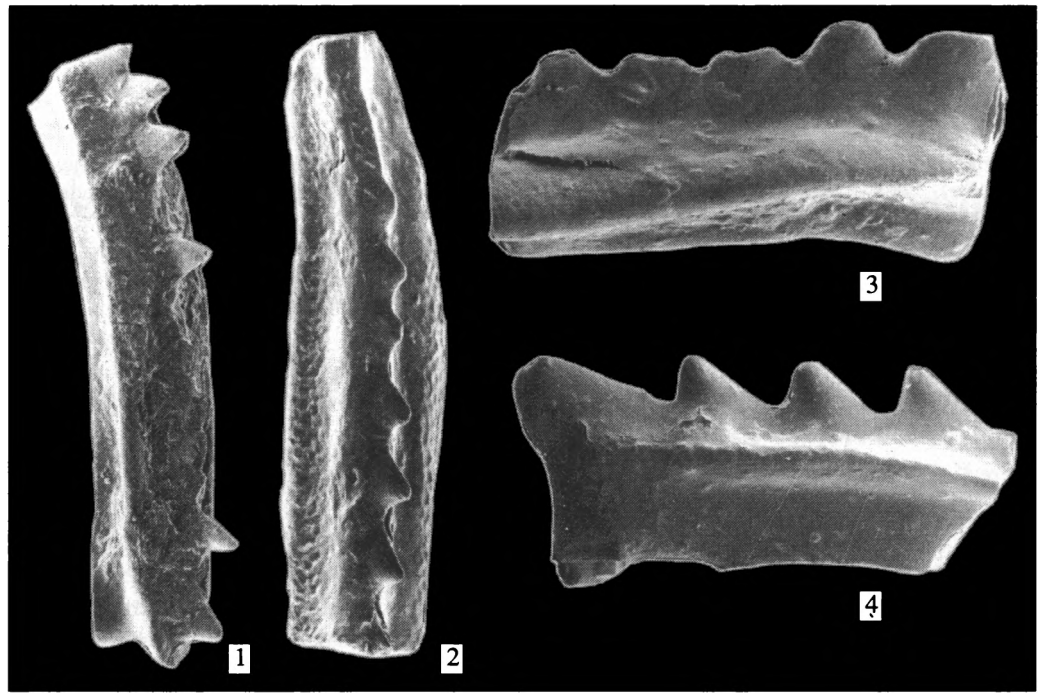

Fig. 2. (1) *Neogondolella foliata* ex gr. *inclinata* (Kovacs) specimen 635/1, lateral and apical sides, ×101, sample 635, Stantsiya Lagoon, Kotel'nyi Island, Upper Triassic, lower Carnian; (2 and 3) *Neogondolella* ex gr. *navicula* (Huckriede): (2) specimen 635/2, apical side, ×138, sample 635, and (3) specimen 635/3, lateral side, ×126, sample 635, Kotel'nyi Island, Tikhaya River basin, Upper Triassic, lower Carnian; (4) *Neogondolella hallstattensis* (Mosher), specimen 635/4, lateral side, ×188, sample 635, Kotel'nyi Island, Tikhaya River basin, Upper Triassic, lower Norian.

ex gr. *inclinata* Kovacs, fragments of *Neogondolella* sp., and two types of ramiform elements (Fig. 2).

The Norian deposits of Kotel'nyi Island are exposed in lower courses of the Tikhaya River (Exposure 190, see Fig. 1b). Here the 15-m-thick Member 8 consists of dark-gray shaly pelitomorphic nonlaminated clays with rare intercalations of thin (0.1 m) concretionary clayey limestone. The clays contain abundant *Halobia* shells, among which valves of *Halobia fallax* Mojs are dominant. The rocks also enclose remains of large *Proclydonautilus* cf. *natosini* McLearn. and *Rhacophyllites* sp. A concretion of clayey limestone, which was sampled at the level of 2 m above the member base, yielded rare conodonts *Neogondolella* ex gr. *navicula* (Huckr.).

The 36-m-thick Member 10 of the section is composed of black shaly clays bearing rare siderite and phosphate concretions. Various *Halobia* forms with dominant *Halobia aotti* Kob. et Ichik. are dispersed through the entire member section. Such forms as *Halobia fallax* Mojs. and *H. obruchevi* Kipar were identified at the level of 6 m above the base. At the level of 10 m, the two latter species associate with *H. kawadai* Yehara and other forms. In addition, this member encloses randomly scattered remains of brachiopods, nautiloids, and ammonoids, the latter including *Pterosirenites obruchevi* (Bajarunas). Conodonts *Neogondolella* ex gr. *navicula* (Huckr.) and juvenile *Neogondolella hallstattensis* (Mosher) (see Fig. 2) were distinguished at the distance of 4 m above the member base.

BIOSTRATIGRAPHIC ANALYSIS

Conodonts from studied deposits of the region can be divided into two assemblages. The lower one is confined to Member 16 and comprises *Neogondolella foliata* ex gr. *inclinata*, *Neogondolella* sp., and ramiform elements. According to Kovacs (1983), the first occurrence level of *Neogondolella foliata inclinata* is at the base of the upper Ladinian. This species is also known from the upper Ladinian (Langobardian) and lower Carnian (Cordevolian–Julian) deposits of northern Hungary, where it occurs in association with *Neogondolella foliata foliata* (Bud.), *Metapolygnathus diebeli* (Kozur), and *Gladigondolella tethydis* (Huckr.). The presence of *Neogondolella foliata* ex gr. *inclinata* in the assemblage suggests that Member 16 most likely corresponds to the *diebeli* (Cordevolian) and *tethydis* (Julian) zones of the standard conodont zonation after Kozur (1980). The identified conodont species and associated *Halobia* forms show that their host rocks most likely are early Carnian in age.

The next assemblage from members 8 and 10 includes *Neogondolella* ex gr. *navicula* and *Neogondolella hallstattensis* (Mosher). As suggested by Krystyn (1980), *Neogondolella navicula* occurs in the

lower–middle Norian (Lacian–Alaunian). This species is known from sections of Europe (Mosher, 1968, 1973; Krystyn, 1980; Kozur, 1980), British Columbia (Mosher, 1968, 1973) and the Far East (Dagys *et al.*, 1987). At the same time, the presence of *Neogondolella hallstattensis* indicates that members in question are correlative with the *spatulata* Zone of the conodont zonation after Hallstatt, the equivalent of the *magnus* Zone in the ammonite scale (Krystyn, 1980), and with the lower Norian Substage in the Far East (Dagys *et al.*, 1987; Burii, 1989). The distinguished conodonts and species of *Pterosirenites obruchevi* (Bajarunas) from Member 10 point to the early Norian age (the *obruchevi* Zone) of members 8, 9, and 10, whose total thickness is 71 m.

Conodont occurrences in Kotel'nyi Island are confined to the monotonous sequence of shales and shaly clays, which is insignificant in thickness. It appears to have been deposited at a slow sedimentation rate, presumably far away from the coast of a paleobasin. Conodonts, discovered from Upper Triassic deposits of North Siberia, are of particular interest for stratigraphers and paleontologists, because, in addition to traditional groups of fossils, they can be used in solving respective problems of biostratigraphy.

The conodont collection is stored under no. 635 at the Monographic Department of the Geological Museum, Institute of Geology, Siberian Division, Russian Academy of Sciences (Novosibirsk).

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REFERENCES

Burii, G.I., *Konodonty i biostratigrafiya triasa Sikhote-Alinya* (Conodonts and Triassic Biostratigraphy of Sikhote Alin'), Vladivostok: Dal'nevost. Geol. Inst., 1989.

Dagys, A.A., Oldest Conodonts from Olenek Region of Northern Siberia, in *Bio- i litostratigrafiya triasa Sibiri* (Triassic Bio- and Lithostratigraphy of Siberia), Moscow: Nauka, 1982, pp. 55–59.

Dagys, A.A., *Rannetriasovye konodonty Severa Srednei Sibiri* (Early Triassic Conodonts from Northern Mid-Siberia) Moscow: Nauka, 1984a.

Dagys, A.A., New Assemblage of Early Triassic Conodonts from Northern Mid-Siberia, in *Stratigrafiya, fauna i flora triasa Sibiri* (Triassic Stratigraphy, Fauna, and Flora of Siberia), Moscow: Nauka, 1984b, pp. 18–22.

Dagys, A.A., Conodonts from the Lower Olenekian Deposits in the Northeastern USSR, in *Biostratigrafiya mezozoya Sibiri i Dal'nego Vostoka* (Mesozoic Biostratigraphy in Siberia and the Far East), Novosibirsk: Nauka, 1986, pp. 57–63.

Dagys, A.A., Triassic Conodonts from the Northeastern USSR, in *Biostratigrafiya i paleontologiya triasa Sibiri* (Triassic Biostratigraphy and Paleontology of Siberia), Novosibirsk: Nauka, 1991, pp. 3–13.

Dagys, A.A., Arkhipov, Yu.V., and Bychkov, Yu.M., *Stratigrafiya triasovoi sistemy severo-vostoka Asii* (Stratigraphy of Triassic System in Northeastern Asia), Moscow: Nauka, 1979.

Dagys, A.S, Dagys, A.A., and Klets, T.V., Problems of Triassic Biostratigraphy and Paleobiogeography in Exotic Blocks of the Northwestern Pacific, in *Yarusnye i zonal'nye shkaly Boreal'nogo mezozoya SSSR* (Stage Scale and Zonation of the Boreal Mesozoic in the USSR), Moscow: Nauka, 1989, pp. 52–60.

Dagys, A.A., Klets, T.V., and Shevelev, E.K., Conodonts from Siliceous Permian and Triassic Deposits of Central Sikhote Alin', *Tr. Inst. Geol. Geofiz., Sib Otd. Akad. Nauk SSSR*, 1987, vol. 689, pp. 4–20.

Egorov, A.Yu., Bogomolov, Yu.A., Konstantinov, A.G., and Kurushin, N.I., Stratigraphy of Triassic Deposits in Kotel'nyi Island (New Siberian Islands), in *Boreal'nyi trias* (Boreal Triassic), Moscow: Nauka, 1987, pp. 66–80.

Kovacs, S., On the Evolution Exelsa-Stock in the Upper Ladinian–Carnian (Conodonta, Genus *Gondolella*, Triassic), *Ostern. Akad. Wissn., Erdwissn. Komm.*, 1983, no. 5, pp. 107–119.

Kozur, H., Revision der Conodonenzonierung der Mittel- und Obertrias des tetyalen Faunenreichs, *Geol. Palaont. Mitt. Innsbruck*, 1980, vol. 10, nos. 3/4, pp. 79–172.

Krystyn, L., Stratigraphy of Hallstatt Region, *Abhandl. Geol. Bundesanst.*, 1980, vol. 35, pp. 69–98.

Mosher, L.C., Triassic Conodonts from Western North America and Europe, and Their Correlation, *J. Paleontol.*, 1968, vol. 42, no. 4, pp. 895–946.

Mosher, L.C., Triassic Conodonts from British Columbia and the Northern Arctic Islands, *Bull. Geol. Surv. Can.*, 1973, no. 222, pp. 141–192.

Terekhov, M.I., and Dylevskii, E.F., *Geologiya khrebta Arga-Tas* (Geology of the Arga-Tas Ridge), Magadan: Sev.-Vost. Kompl. Nauch.-Issled. Inst., 1988.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 616–621. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 99–104.
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BRIEF COMMUNICATIONS

The Pontian-Caspian Region as a Possible Stratoregion of the European Pleistocene

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Key words: *Pleistocene, correlation, biostratigraphy, endemic fauna, marine and brackish-water faunas, transgressions, regressions.*

The Pleistocene biostratigraphy of the Caspian region is based on changes in assemblages of brackish-water mollusks, predominantly cardiids of the genus *Didacna* Eichwald. Because of the endemic character of this fauna, the Caspian Pleistocene scale has a local significance and is awkwardly correlative with that of Western Europe.

A few decades ago, it was a common practice to correlate geological events of the Caspian and Black Sea regions with the stratigraphic sequence of well-studied glacial deposits of the Russian Plain, which was taken as a standard. However, when drilling in the Don River valley had uncovered some unknown glacial horizons of the middle and lower Pleistocene, this approach to correlation became complicated. At the same time, the marine Pleistocene stratigraphy of the Pontian-Caspian area appears to have been adequately studied by means of integrated biostratigraphic, geomorphologic and lithologic-facial analyses, and sometimes by radiometric dating.

Long study on natural outcrops and drilling data from the coasts and shelves of the Caspian and Black seas revealed that some Pleistocene horizons of the Black Sea region contain faunal elements of Caspian origin in addition to local fauna. It has been long established that in the Chaudan deposits of the Kerch' Peninsula (Cape Chauda), local *Didacna pseudocrassa* Pavl., *D. olla* Livent., *Tschaudia tschauda* Andrus., and others occur together with *Didacna rudis* Nal., *D. carditoides* Andrus., and others typical of the Bakunian deposits of the Caspian area (Fedorov, 1963, 1978, 1993).

The Bakunian *Didacna rudis* Nal. and *D. carditoides* Andrus. were also found in the Chaudan terrace of the Caucasian coast and in the upper Chaudan deposits of Guriya (western Georgia). Finally, the drilling in the Manych depression recovered a gradual transition of the Bakunian deposits into the Chaudan-Bakunian beds (Goretskii, 1970; Popov, 1983). In the northern coast of the Taman' Peninsula, a terrace 35–37 m high, which contains *Didacna parvula* Nal., *D. baericrassa* Pavl., and others, was interpreted as Chaudan-Bakunian (lower Bakunian) in age.

This enables us to correlate directly the Bakunian and Chaudan deposits. The most complete Chaudan section in Cape Chauda proves the correlation between the lower Bakunian and lower Chaudan beds (there is *Didacna parvula* Nal. in both of them) and between the upper Bakunian and upper Chaudan beds (with common *Didacna rudis* Nal., *D. carditoides* Andrus., and *D. eulachia* (Bog) Fed.). It should be added that the Chaudan deposits are known from the southern part of Dardanelles (Andrusov, 1965; Keraudren, 1971, 1979), where they grade into marine deposits with Mediterranean fauna. This work is intended to establish biostratigraphic correlations of the main Pleistocene subdivisions of the Pontian-Caspian region with the Pleistocene scales for the Mediterranean and all of Europe. As mentioned above, in the Manych depression, the Kerch' and Taman' peninsulas, and the Caucasian coast, the Chaudan-Bakunian deposits of the lower Pleistocene contain the Bakunian cardiids *in situ* together with mollusks of Black Sea origin.

The Chaudan brackish-water basin probably extended as far as the Marmara and northern Aegean seas, as evidenced by the occurrence of the Chaudan fauna in the southern Sea of Marmara area. This was in the period of the low stand of the Mediterranean Sea level. The subsequent rise in sea level resulted in salt-water inflow into Dardanelles (marine fauna in the deposits overlying the Chaudan beds in Gallipoli and Murefte-Chora).

The same event has been recently recorded in the Black Sea coasts. This basin is the most isolated inland sea on Earth. At times, it turned into a brackish-water lake basin analogous to the Caspian Sea when the latter cast off its waters into it. In other periods of the interglacial transgressions of the Mediterranean Sea, it became a part of this basin. The alternation of the Caspian and Mediterranean horizons in the Pleistocene sequence of the Black Sea opens new possibilities for geological correlations and paleogeographic reconstructions

of the Caspian, Black and Mediterranean sea areas in the latest geological period.

The younger Paleoeuxinian Horizon of the Black Sea sequence, which contains the Caspian molluscan fauna, has a two-member structure. This can be best observed in the Caucasian coast, where independent lower and upper Paleoeuxinian terraces occur (Fedorov, 1963, 1978).

Deposits of the first terrace contain small-sized carinate *Didacna*, similar to the early Khazarian *D. subpyramidata* Prav. and *D. pallasi* Prav.

The upper Paleoeuxinian deposits include *Didacna nalivkini* Wass. and other species characteristic of the younger horizons of the lower Khazarian in the Caspian area, along with local *Didacna pontocaspia* Pavl. The molluscan assemblage from the Ozernoe (Babel') section, which includes both local Paleoeuxinian cardiids and the early Khazarian *Didacna pallasi* Prav. and *D.* ex gr. *nalivkini* Wass., is very demonstrative (Fedorov, 1978). Undoubtedly, the spill of the Caspian waters through the Manych Strait into the Azov and Black seas resulted in the dispersal and acclimatization of mollusks both in the Bakunian and early Khazarian times. As in the Chaudan-Bakunian Age, the Mediterranean Sea level was low at the Paleoeuxinian time and brackish waters with cardiids of the Caspian type flowed through the system of straits and the Sea of Marmara into the Aegean Sea. The subsequent Mediterranean transgression led to the salt-water inflow into the Black Sea and the dispersal of semimarine fauna of the Mediterranean type there. The late Khazarian basin also cast off its waters into the Azov–Black Sea basin. The respective evidence is obvious in the western Manych depression (Popov, 1983), but there are no similar records in the Azov and Black seas. According to general paleogeographic reconstructions and radiometric data, the late Khazarian phase of the Caspian evolution occurred after the Karangatian transgression (the first is dated as about 100 ka old, and the age of the second is about 110–120 ka). The latest inflow into the Azov–Black Sea depression from the Caspian Sea was during the early Khvalynian transgression, when the Caspian Sea level rose first by up to 47 m and then up to 22–25 m. These levels are distinctly pronounced in the geomorphology and are substantiated by molluscan faunas all over the Caspian coasts, including the western part of the Manych depression (Popov, 1983; Fedorov, 1994). Because the post-Karangatian regression occurred in the Black Sea at that time, the early Khvalynian inflow should be recorded in the bottom sediments. In the northeastern coast of Cape Kazantip, the Kerch' Peninsula, 8- and 18-m-high terraces, which contain brackish-water cardiids of the Khvalynian type, may indicate the former existence of an intermediate basin affected by the early Khvalynian inflow into the Azov depression.

Thus, the lower and middle Pleistocene deposits of the Pontian-Caspian area can be directly correlated by the biostratigraphic data. Correlations between younger horizons need to be substantiated by other methods, including radiometric dating, in addition to the biostratigraphic data.

The correlation of geological events in the Black and Mediterranean seas is considerably more complicated.

It should be taken into account that all the transgressive phases in Black Sea evolution were induced by the Mediterranean transgressions, which took place, as a rule, during interglacial thermal maxima. There might be as many transgressions in the Black Sea as in the Mediterranean Sea, but not more. In fact, the former were less frequent, because not every global transgression could overcome the Bosporus threshold. The direct biostratigraphic correlation is only evident between the Karangatian of the Black Sea and the Tyrrhenian of the Mediterranean, which corresponds to the Riss/Würm (Eemian) and is dated now as 80–120 ka.

In the 1970s, special investigations, which were carried out by a group of scientists from France, Spain, Italy, and Tunisia in the North African, Italian and Spanish coasts, enabled them to subdivide the Mediterranean Tyrrhenian into three parts: Douira (first phase), Rejiche (maximal phase, or main Tyrrhenian), and Chebba (regressive phase) (Paskof and Sanlaville, 1983). The same succession can be observed in the most complete Karangatian section near the Geroevskoe (El'tigen') Village (the eastern Kerch' Peninsula) and partly in the northeastern coast of Lake Chokrak (the northern Kerch' Peninsula). The two-member Karangatian structure (excluding the upper unit corresponding to the regressive phase) was recovered by drilling in the Kerch' Strait (Fedorov, 1978) and the Black Sea shelf.

Taking the Karangatian as a reference point, we can outline a correlation between some later events and the Mediterranean history. It is now obvious that the Surozhian beds taken by Goretskii (1970), Popov (1983), and other authors as evidence of the Black Sea transgression in the middle Würm are actually upper Karangatian deposits older than 80–90 ka.[1] It is significant that the coastlines marking the Karangatian and Tyrrhenian interglacial transgressions in the Black and Mediterranean seas are recorded at the nearby levels: 12–15 and 20–25 m. This suggests that these levels were not affected by tectonic activity.

The Holocene events of both basins are highly correlative. The global postglacial Flandrian transgression, which began from melt-water supply in the terminal Würm Glacial, developed spasmodically, beginning with the sea level, which was initially at –120 or –130 m and then exceeded the present oceanic level.

In the Black Sea area, this process manifested itself first in the appearance of the flow-through brackish-

[1] Age measurements recently obtained by Kh.A. Arslanov (pers. commun.).

water Neoeuxinian basin and a backwater in the Bosporus. Afterwards, when the Mediterranean (oceanic) level exceeded the Bosporus threshold, the Mediterranean waters and marine fauna began to penetrate into the Black Sea.

The development of the Black Sea Holocene transgression was analogous to the succession of events in the Mediterranean Sea. The beginning of the inflow from the Mediterranean into the Black Sea 7–9 ka ago is stratigraphically marked by the event, when the light-gray clays and silts with the Neoeuxinian *Monodacna* and *Dreissena* were replaced by dark-gray clays with *Cardium edule* L., *Monodacna* and *Dreissena* of the early Chernomorian age. In the coastal areas, there are occasional insignificant hiatuses. However, in some places, where the contact between these deposits is less distinct, the Neoeuxinian and early Chernomorian beds seem to represent a single transgressive stratum.

The Chernomorian Horizon can be divided into two main parts: the lower Chernomorian beds, which are predominantly represented by clays with *Cardium edule* L. and other species, and the upper Chernomorian beds, which are represented by sands and coquinas with rich Mediterranean fauna. The latter beds compose a coastal terrace 3–5 m high, which marks the highest sea level in the middle Holocene. With allowance for a storm surge during the formation of the terraces, this level is estimated to be 2 m higher than the present sea level. The terrace as well as the maximal phase of the Flandrian is dated as about 5 ka old.

In the interval between 3 and 2 ka, the Fanagorian regression resulted in a sea-level fall down to –5 or –7 m. At about 1 ka ago, it was followed by the Nimfean transgression, when the sea level rose up to 0.5–1 m above the present one. This transgression may correspond to the formation of the Dunkirk terrace in Western Europe.

Thus, reliable correlations can be established between the upper Pleistocene deposits of the Mediterranean and Black seas. Beginning from the early Chernomorian time, the Holocene evolution of the Black Sea reflected (even in detail) the course of the Flandrian transgression in the Mediterranean and in Western Europe. It is natural to assume that the history of the Black Sea, in as much as it communicates with the Mediterranean Sea, may help in understanding the evolution of the latter: the Mediterranean interglacial terraces can be paleontologically differentiated only by thermophylic peculiarities of mollusks, whereas the Mediterranean horizons of the Black Sea sequence are well recognizable and can be reliably correlated to those of the Caspian phases. This provides a new basis for correlating the lower and middle Pleistocene deposits in the Black Sea and Mediterranean regions.

Some evidence of a Mediterranean phase in the history of the Black Sea, which occurred immediately after the Chaudan time, was known from Gallipoli and Murefte-Chora in the Sea of Marmara (Keraudren, 1971) and Tsvirmagal Mountain in Guriya. Recently, the records became available from capes Idukopas and Chauda, where the uppermost Chaudan beds yielded foraminifers (Yanko, 1989). This justifies the assumption of the subsequent salinization of the Chaudan basin as a result of the early Pleistocene interglacial transgression from the Mediterranean Sea. However, this marine phase that I called "Epi-Chaudan" has not yet been definitely dated. This phase is commonly correlated with the Milazzian. Although the Milazzian stratotype has been recently doubted, I suppose, following Keraudren (1971), that this Mediterranean interglacial transgression took place prior to the Roman (Mindel) regression, probably in the warm Cromerian. This succession of events corresponds to the formation of terraces during the Chaudan and early Paleoeuxinian sedimentary cycles separated by the long-term (and probably significant) Venedian (Mindel) regression in the Pontian-Caspian area.

In the middle Pleistocene deposits of the Black Sea, Arkhangel'skii (1938) recognized the Uzunlarian beds with molluscan fauna of mixed Caspian-Mediterranean origin. The beds were considered to be younger than the Paleoeuxinian but older than the Karangatian. Thorough investigations of the Lake Uzunlar stratotype of the Kerch' Peninsula, which were carried out by Chepalyga (1986), proved the stratigraphic position of the Uzunlarian beds. In particular, it was shown that they represent an independent unit that could not be assigned to the lower Karangatian.

These stratigraphic relationships can also be well observed in the Pshada and Agoi interfluve of the Caucasian coast.

The Uzunlarian marine beds are usually correlated with the Oditsovo interglacial deposits of the Russian Plain (the Riss-I/Riss-II Interglacial in Western Europe). They are likely to correspond to an ancient (pre-Riss/Würm) interglacial transgression from the Mediterranean Sea that was established by Zeuner (1959).

In the Caucasian coast to the south of the town of Tuapse, the beds with Mediterranean fauna compose a terrace 40–45 m high that is superimposed onto the upper early Euxinian terrace, partly overlying its deposits. The detailed study of these marine terraces and their sedimentary covers in this region suggests that these beds, which I called "Paleouzunlarian", are undoubtedly older than the Uzunlarian (Fedorov, 1963, 1978). The Epi-Chaudan and two middle Pleistocene phases of the Black Sea salinization were documented in the deep-sea drilling site of "Glomar Challenger" in 1975. The drilling materials were studied by Russian specialists—A.P. Jouse, V.V. Mukhina, and E.V. Koreneva (*Geological ...*, 1980). Analysis of spore-pollen and diatom assemblages allowed them to recognize some hydrological changes in the basin. It was established that brackish- and cool-water environments were replaced by salt- and warm-water conditions in the late

Stratigraphic correlation of Pleistocene sequences of the Caspian, Black and Mediterranean seas and Western Europe

ISC Scale		Western Europe	The Mediterranean Sea (figures denote sea levels)		Direction of flow	Black Sea (figures denote sea levels)		Direction of flow	Caspian Sea (figures denote sea levels)	
Holocene		The Dunkirk terrace	Flandrian (transgression from –30 m to +2 m)		→	Chernomorian	Neochernomorian (1–2 m)		Neocaspian	Upper (–21 m)
		Flandrian (second phase)					Paleochernomorian (–20 m)			Lower (–24 ... –25 m)
									Mangyshlak regression (–50 m)	
Pleistocene	Upper	Würm (oceanic regression down to –120 or –130 m)	Lower Flandrian (transgression from –50 to –30 m)		←	Neoeuxinian (–40 ... –20 m)			Khvalynian	Upper Khvalynian (–2 m)
			Grimaldian (regression down to –100 or –130 m)		←	Post-Karangatian (regression down to –90 m)		←		Lower Khvalynian (47 m)
		Riss/Würm (Eemian)	Tyrrhenian	Chebba	→	Karangatian	Upper (main) Karangatian	← ?	Atelian regression	
				Rejiche (Eutyrrhenian)					Upper Khazarian	
				Douira	→		Lower Karangatian		Regression	
	Middle	Riss-II	Regression		←	Regression		← ?	Lower Khazarian	Kosogian
		Riss-I/Riss-II	Mesotyrrhenian		→	Uzunlarian				Regression
		Riss-I	Regression		←	Upper Paleoeuxinian		←		Singilian
		Mindel/Riss (Holsteinian)	Paleotyrrhenian		→	Regression				Regression
						Paleouzunlarian				Paleosingilian
		Mindel	Roman regression (long-term)		← ←	Lower Paleoeuxinian		←		
						Venedian regression (long-term)			Venedian regression (long-term)	
	Lower	Cromerian	Millazzian		→	Chauda	Epi-Chauda	←	Bakunian	Urundzhik
					←		Upper Chauda			Upper Bakunian
							Lower Chauda			Lower Bakunian
		Glaciation (Günz)	Regression (long-term)		←		Regression (long-term)			Tyurkyan regression (long-term)
Upper Pliocene (Eopleistocene)			Emilian Calabrian		←	Guriyan		←	Apcheronian	

Chaudan (Epi-Chaudan), at the end of the early Paleoeuxinian (Paleouzunlarian), and at the latest Paleoeuxinian (Uzunlarian).

Later, Yanko (1989), who thoroughly studied the Pleistocene foraminifers of the Black Sea, reported on the existence of the pre-Uzunlarian hypersaline basin that had replaced the early Paleoeuxinian basin of the Caspian type. The Paleouzunlarian basin appeared as a result of the Great (Mindel/Riss) interglacial transgression in the Mediterranean (Paleotyrrhenian).

It should be remembered that there were two phases of each transgression in the Black Sea during the early and middle Pleistocene (Fedorov, 1988). In the first phase that coincided with the first half of the interglacial, there was an inflow of water from the Caspian Sea through the Manych depression. In the second phase, which was marked by the interglacial climatic optimum and maximum of the global transgression, the Mediterranean waters flowed into the Black Sea. However, the backwater appeared in the Black Sea straits in the first phase, as evidenced by the occurrence of sparse and impoverished marine molluscan fauna in the lower and upper beds of the Paleoeuxinian.

Thus, the Pleistocene sequence of the Black Sea region shows five Mediterranean horizons alternating with those that have their counterparts in the Caspian area. The correlations between the Mediterranean horizons of the Black Sea and the individual Pleistocene beds (terraces) of the Mediterranean Sea are only valid for the Chernomorian–Flandrian and Karangatian–Tyrrhenian (Riss/Würm) intervals. Although evident, correlations within the Uzunlarian–Mesotyrrhenian, Paleouzunlarian–Paleotyrrhenian, and Epi-Chaudan–warm Cromerian require further study. Radiometric investigations may turn out to be most helpful in this respect.

The Pleistocene correlations of the Pontian-Caspian region discussed above with reference to the Mediterranean Pleistocene scale suggest some paleogeographic inferences, particularly those concerning the water exchange between these basins. It seems obvious that in the Caspian transgressive phases there was one-way drainage (the cascade of seas) into the Black Sea and farther into the Marmara and Mediterranean seas. This drainage was only possible at a low global and Mediterranean sea level, which is commonly considered to be characteristic of glacial epochs. The drainage continued during the initial interglacial transgressions that led to the rise in the Mediterranean Sea level. This is evidenced by the occurrence of marine fauna in the Black Sea deposits accumulated during the Caspian transgressive phases (the early and late Paleoeuxinian). At the maxima of these transgressions (thermal optima of the interglacials) the one-way Caspian–Euxinian–Mediterranean drainage ceased, and the Mediterranean ingression proceeded through Dardanelles, the Sea of Marmara and Bosporus into the Black Sea. In the latter basin the interglacial transgressions occurred in the Epi-Chaudan, Paleouzunlarian, Uzunlarian, Karangatian, and Chernomorian times. They were like an echo of global events in the World Ocean.

The data presented here suggests that the Pleistocene stratigraphy of the Pontian–Caspian region can be considered to be detailed and relatively complete geological records of the Pleistocene events in all Europe.

The Pleistocene sequence of the Black Sea area seems to be of particular significance because it exhibits the alternation between the horizons with the Caspian brackish-water mollusks, which are reliably fixed against the Caspian scale, and the horizons with marine fauna, which can be correlated to the subdivisions of the Mediterranean stratigraphic scale. These correlations help to substantiate further the stratigraphic position of the Mediterranean Pleistocene interglacial horizons (terraces).

The data discussed here and the suggested correlations are presented in the table, the previous versions of which have already been published (Fedorov, 1978, 1993). Actually, the Pleistocene sequence of the Pontian–Caspian area can be suggested as a possible reference section of the European Pleistocene.

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REFERENCES

Andrusov, N.I., The Post-Tertiary Tyrrhenian Terrace in the Black Sea Area, in *Izbrannye trudy* (Selected Works), Moscow: Nauka, 1965, vol. 4, pp. 143–162.

Arkhangel'skii, A.D. and Strakhov, N.M., *Geologicheskoe stroenie i istoriya razvitiya Chernogo morya* (Geological Structure and History of the Black Sea), Moscow: Akad. Nauk SSSR, 1938.

Chepalyga, A.L., Markova, A.K., and Mikhalesku, K.D., Stratigraphy and Fauna of the Stratotype of the Uzunlarian Horizon from the Black Sea Pleistocene, *Dokl. Akad. Nauk SSSR*, 1986, vol. 290, no. 2, pp. 433–437.

Fedorov, P.V., Caspian Quaternary Mollusks of the Genus *Didacna* Eichwald and Their Stratigraphic Significance, in *Stratigrafiya chetvertichnykh otlozhenii i noveishaya tektonika Prikaspiiskoi nizmennosti* (Stratigraphy of Quaternary Deposits and Recent Tectonics of the Caspian Lowland), Moscow: Akad. Nauk SSSR, 1953, pp. 112–150.

Fedorov, P.V., Quaternary Stratigraphy and History of the Caspian Sea, *Tr. GIN, Akad. Nauk SSSR*, Moscow, 1957, no. 110.

Fedorov, P.V., Quaternary Stratigraphy of the Crimea–Caucasus Coast and Some Problems of the Geological History of the Black Sea, *Tr. GIN, Akad. Nauk SSSR*, Moscow, 1963, no. 88.

Fedorov, P.V., Pleistocene of the Pontian-Caspian Area, *Tr. GIN, Akad. Nauk SSSR*, Moscow, 1978, no. 310.

Fedorov, P.V., Changes in the Black Sea Level during the Pleistocene, *Byull. Mosk. O-va Ispyt. Prir., Otd. Geol.*, 1988, vol. 61, no. 4, pp. 56–61.

Fedorov, P.V., The Pontian-Caspian Early Pleistocene, *Stratigr. Geol. Korrelyatsiya*, 1993, vol. 1, no. 1, pp. 137–143.

Fedorov, P.V., Some Problems Concerning the Geological History of the Caspian Sea, *Stratigr. Geol. Korrelyatsiya*, 1994, vol. 2, no. 2, pp. 71–79.

Geologicheskaya istoriya Chernogo morya po resul'tatam glubokovodnogo bureniya (Geological History of the Black Sea according to the Deep-Sea Drilling Data), Moscow: Nauka, 1980.

Goretskii, G.I., *Allyuvial'naya letopis' velikogo Pra-Dnepra* (Alluvial Records of the Great Pre-Dnieper), Moscow: Nauka, 1970.

Keraudren, B., Les formations quaternaires marines de la Grece, *Bull. Musee Prehist.* (Monaco), 1971, vol. 17, pp. 1–176.

Keraudren, B., Le Plio-Pleistocene marin et oligohalin en Grece, *Rev. Geol. Dynam. et Geogr. Phys.*, 1979, vol. 21, pp. 17–28.

Paskof, R. and Sanlaville, P., *Les côtes de la Tunisie variations du niveau marin depuis le Tyrrhenien*, Lyon: Maison de l'Orient Mediterranean, 1983.

Popov, G.I., *Pleistotsen Chernomorsko-Kaspiiskikh prolivov* (The Pleistocene of the Black and Caspian Sea Straits), Moscow: Nauka, 1983.

Yanko, V.V., Quaternary Foraminifers of the Pontian-Caspian Area: Classification, Ecology, Stratigraphy, Evolution, *Doctoral (Geol.–Mineral.) Dissertation*, Moscow: Moscow State Univ., 1989.

Zeuner, F.E., *The Pleistocene Period, Its Climate, Chronology, and Faunal Successions*, London: Hutchinson, 1959.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 622–624. Translated from Stratigrafiya. Geologicheskaya Korrelyatsiya, Vol. 4, No. 6, 1996, pp. 105–107.
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Grigorii Yakovlevich Krymgol'ts: On His Ninetieth Birthday

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Progress in all facets of human evolution, and in different trends of science in particular, is influenced first and foremost by the personal qualities of the leaders, not only by their scientific achievements, but by the virtues of their nature as well. Some of them, possessing commanding qualities, fascinate with fine words, brilliant books, or good looks. Others, not as striking at first glance, acquire authority by their erudition, logic of reasoning, and perhaps most of all by their cordial, almost paternal support and subtle correction of trends in the studies of their colleagues. Grigorii Yakovlevich Krymgol'ts, Professor of Leningrad, now St. Petersburg, University is one of such scientists. He is without exception the rightful leader in Jurassic geology and paleontology in Russia almost throughout the whole of our century and the main "expert" in the former USSR and in Russia nowadays. On January 20, 1997, he will turn 90 years old. What a magnificent and solemn date! Thousands of his followers will congratulate Grigorii Yakovlevich on his birthday: all the students who attended his lectures and talks and read his numerous published papers and books, and all those who were guided by his advice in their scientific studies as ordinary or postgraduate students and professional specialists.

G.Ya. Krymgol'ts was born on January 7 (20 by the Gregorian Calendar), 1907 in Simferopol'. His mother, Dora Grigor'evna, was a teacher of French and his father, Yakov Vladimirovich Krymgol'ts, was an executive of the Krympotrebsoyuz company. The family, as testified by Grigorii Yakovlevich, was hard-working and closely knit. It endowed Grigorii Yakovlevich with such personal qualities as equanimity, regard for his associates, an honest and unassuming manner, and a certain reticence. These characteristic features make a true impression of profound wisdom in and give rise to unqualified respect in everyone who knows him.

After finishing high school in Simferopol' in 1924, G.Ya. Krymgol'ts went to Petrograd and entered the Section of Natural Sciences (Geological–Mineralogical) of the Physical–Mathematical Faculty of the University. In 1929, he graduated from the University with high marks and started his career at the Geological Committee of the All-Union Council of the National Economy (VSNKh) of the USSR, later the Karpinskii All-Union (All-Russia) Geological Institute (VSEGEI). He worked there till 1948, but he never actually severed his scientific activities with this geological center, the largest in Russia. In the year of his graduation, Grigorii Yakovlevich published his first monograph *The Upper Jurassic Cylindroteuthinae from Timan, the basin of the Sysol River, and the Orenburg Province* (1929). This publication brought the young researcher the authority of a specialist in paleontology. The materials used in the book were derived from Jurassic deposits, which became the main object of his scientific interests throughout his life. This capacity for an amazing tenacity and loyalty towards his attachments has been one of his remarkable traits. Grigorii Yakovlevich studied the Jurassic System in the Crimea, the North Caucasus, the Pamirs, Turkmenistan, and the Far East; he also received and studied numerous collections of fossil organisms from other areas of Jurassic deposits. As a result, as early as the 1930s, G.Ya. Krymgol'ts became one of the generally recognized experts in this system

and its biofossils. By that time, he had published four monographs and several articles on Jurassic deposits and their organic remains from different regions of the Soviet Union. In these works he was the first to discuss the systematics of belemnites and their role in detailed Jurassic stratigraphy and to give a comprehensive description of this stratigraphic system. Many of his publications are still relevant and are referred to in publications. In 1937, he got his Candidate degree in Geological–Mineralogical Sciences without the official defense procedure.

During the Second World War, Grigorii Yakovlevich Krymgol'ts and a group of his colleagues were officially attached to the Turkmenistan Geological Department. He conducted geological and hydrogeological surveys in the mountain and desert areas of Turkmenistan, where he, as a youth, worked under the guidance of V.F. Pchelintsev.

After the war, in 1948, Grigorii Yakovlevich was back in Leningrad as Associate Professor of the Chair of Historical Geology at Leningrad University, where he had worked as Assistant Lecturer from 1932. In 1965 he received the Professor's Chair. The University was the place where his talent as a wonderful teacher and true scientist was demonstrated to full advantage. In this period he wrote his basic works on stratigraphy, paleontology and paleogeography of the Jurassic System and prepared the splendid academic courses "Historical Geology," "The Stratigraphic Practical Course (MZ)," "The Problems of the General Stratigraphic Scale (MZ)," among others. By supervising the preparation of undergraduates' theses, graduation papers, and doctoral dissertations, Grigorii Yakovlevich has brought up a large number of outstanding specialists, both Russian and foreign, in the field of stratigraphy and paleontology of mainly Mesozoic formations. Among his 24 postgraduates are well-known academicians and professors in Russia and Ukraine, in the Caucasus and states of Central Asia, in Rumania, Germany, Viet Nam, the United States, and other countries. He has numerous disciples beyong his formal pupils, whose scientific career was formed under his guidance and counsel.

The prodigious erudition of Grigorii Yakovlevich and his splendid knowledge of the problems of Jurassic stratigraphy and fauna were unanimously acknowledged by his colleagues when they elected him Chairman of the Jurassic Commission of the Interdepartmental Stratigraphic Committee (ISC) at its inauguration in 1955. G.Ya. Krymgol'ts held this position until 1985, when he passed it over to M.S. Mesezhnikov, one of his most talented colleagues. Grigorii Yakovlevich, now the Honorary Chairman of the Jurassic Commission, still actively participates in all its enterprises. During the 30 years of his chairmanship, the Commission was one of the most active. At its regular Plenary Sessions and meetings, lively discussions were held on the problems of Jurassic stratigraphy and regional and interregional paleogeographic schemes, and afterwards the results were promptly published. No wonder that the zonal standard of the Jurassic System adopted in 1978 had the fewest corrections in later years as compared with similar issues of other commissions. The productive activity of the Jurassic Commission was an obvious result of the uncommon organizing ability of its Chairman.

It is quite natural, as a consequence, that Grigorii Yakovlevich represented our country for many years at the International Subcommission on Jurassic Stratigraphy, of which he was a permanent member, and in several sessions of the International Geological Congress and other international meetings.

Among the outstanding achievements of G.Ya. Krymgol'ts we should mention the organization in 1956 of a small group of colleagues, postgraduates and students of the University for the study of stratigraphy and organic remains of the Jurassic and Lower Cretaceous deposits in Central Asia, mainly in Turkmenistan. At first, the group represented a part of the VSEGEI Central Asia Expedition organized at that time. But since 1959, the group became the autonomous Turkmenistan Expedition of the Leningrad University. It worked by contract with the Turkmenian Geological Administration, the All-Union Scientific Research Institute of Geology and Mineralogy, the Scientific Research Institute of Geology of Foreign Countries, and others. The expedition worked until 1991 and made an impressive contribution to the study of Mesozoic geology in the western part of Central Asia. Its results have substantially improved our knowledge of the stratigraphy, fauna, paleogeography, and tectonics of the whole Jurassic System and the Lower Cretaceous. Its data have effectively verified the prediction of oil and gas deposits, have helped to discover the largest celestine deposit in Central Asia, to estimate the molybdenum and barite mineralization, along with distribution of reserves of commercial and building materials, and to create the stratigraphic basis for the legends of large-scale geological maps of certain parts of the stratigraphic section. Many colleagues from Leningrad University and from a number of Turkmenistan geological organizations, and scores of students have acquired the skills of geological research by working in the staff of the expedition. The scientific results were published in several monographs and summaries and in many dozens of articles. The materials of the expedition were used in more than ten Candidate and three Doctoral dissertations. And only the current economic and political crises have halted the activity of the Turkmenistan Expedition created by G.Ya. Krymgol'ts.

Besides all that, he was a wonderful organizer and leader of international and all-union meetings combined with long geological excursions in the European part of Russia, the Caucasus, Kazakhstan, Central Asia, and Siberia. Everyone lucky enough to take part in this activity still remembers these fascinating trips, which

expanded the outlook of specialists and united Jurassic stratigraphers and paleontologists in a still closer cooperation. The success of these ventures was largely brought about by the unassuming, wonderfully tactful, quiet guidance and efficient activity of the Chairman of the Jurassic Commission.

What, in short, characterizes Grigorii Yakovlevich Krymgol'ts as a scientist? What is his actual personal contribution to science? First, a deeper penetration into the subject of his main interests: paleontology and stratigraphy of the Jurassic system. Second, a comprehensive and encyclopedic knowledge of these subjects.

The paleontological studies of G.Ya. Krymgol'ts mainly cover the basic guide fossils of the Jurassic period: ammonites and belemnites. Their systematics, description, methods of study, and distribution in space and time are discussed in numerous papers, six monographs, and atlases of the USSR and Turkmenistan. He also was editor (and coauthor) of the volume *The Fundamentals of Paleontology* dedicated to cephalopod mollusks. His works *The Methods of Collecting and Processing the Paleontological and Stratigraphic Materials* (1954) and *The Methods of Determination of Mesozoic Cephalopod Mollusks* (1960) were translated into Polish.

In this country, G.Ya. Krymgol'ts is recognized as the leading stratigrapher and as an expert and creator of the general stratigraphic scale of the Jurassic System. His publications on the stratigraphy of the Lower and Middle Jurassic and their boundaries, and works on the Aalenian, Bajocian and Callovian stages have made a deep impression in the stratigraphy of this country and abroad. He was the permanent editor and author of the principal generalizations in stratigraphy and geology of the Jurassic System in the volumes *Geology of the USSR*, *Stratigraphy of the USSR*, *Paleogeography of the USSR*, etc. Grigorii Yakovlevich, in collaboration with M.S. Mesezhnikov, was the initiator of the work, *The Zones of the Jurassic System in the USSR* (1982), which was the first of its kind. It was translated into English in the United States (1986) and received worldwide recognition.

Mainly through the efforts of Grigorii Yakovlevich, the foundations for research in Jurassic stratigraphy were laid in Turkmenistan, the northern Caucasus, Yakutia (Sakha), the North European part of Russia, and the Far East. He introduced the new stratigraphic term "lona," now extensively applied; however, the full appreciation of this term in stratigraphy is yet to come.

This exposition of his scientific achievements is far from complete. The activity of Grigorii Yakovlevich Krymgol'ts, his perseverance in his chosen course, his high sense of responsibility, and his kindness and willingness to help are the wonderful features that may serve as an example and a guide to his younger colleagues.

The collaborators and grateful disciples and friends of Grigorii Yakovlevich Krymgol'ts warmly congratulate him on this wonderful occasion and hope for the repeated benefit of his advice.

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CHRONICLE

Fifty Years of Riphean Geology (All-Russian Conference on General Problems of Stratigraphy and Geological History of the Riphean in Northern Eurasia)

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The All-Russia Conference General Problems of Stratigraphy and Geological History of the Riphean in Northern Eurasia was held between November 14–16, 1995. It was organized by the Institute of Geology and Geochemistry of the Ural Division of the Russian Academy of Sciences (IGG UD PAS), Ural divisions of the Interdepartmental Lithologic and Tectonic Committees, Ural Regional Interdepartmental Stratigraphic Commission, and by the Ural State Mining Academy with the assistance of Geological Committees of the Ural region. The conference was supported financially by the Russian Foundation for Basic Research (project no. 95-05-16942).

The conference marked the 50-year anniversary of Schatsky's (1945) first identification, based on *ancient fossil-free formations of the Bashkirian Mountains*, of an independent Upper Proterozoic rock assemblage that preceded the Cambrian. Later, analogues of these deposits were discovered in several other regions, and the term "Riphean" was widely used in stratigraphic practice. Sokolov (1952) united the youngest Precambrian rocks into a separate Vendian System, and more precisely identified the range of the Riphean. The latter was considered to comprise three groups of the Bashkirian meganticlinorium: Burzyanian, Yurmatian, and Karatavian. Recently, the Riphean and Vendian were accepted as basic units of the Upper Precambrian scale of Russia and widely cited in foreign publications dealing with the Late Proterozoic biosphere. The stratotype of the Riphean on the northern slope of the southern Urals comprising three of the above-mentioned groups is one of the most representative among the sequences, which could serve as a standard to subdivide the global chronostratigraphic scale of the Precambrian.

The Riphean, whose chronological range extends between 1.65 and 0.65 Ma, is one of the largest and most specific stages in the evolution of the earth's lithosphere and biosphere, and corresponding deposits actually represent a major stratigraphic subdivision. In the evolution of the earth's outer shells, this stage is associated with the following important events: (1) the formation of the platform sedimentary cover in giant cratons; (2) the beginning of their destruction due to the extension processes in mobile belts and subsequent breakup of the supercontinent; (3) essential changes in ecosystems and climate; (4) a wide development of eucariotes; (5) first appearance of organisms resembling Metazoa; and (6) significant paleogeographic reorganizations. Specific features of the tectonic history of the Riphean determined its metallogenic peculiarities. Hydrocarbon deposits and occurrences are associated with the Riphean sedimentary basins. Now, the assessment of the oil and gas potential of these deposits attracts the particular attention of specialists.

The conference attracted over 90 scientists from various scientific organizations. They represented institutes of the Russian Academy of Sciences, research institutions of the Committee for Geology of the Russian Federation, universities, and other organizations from various cities of Russia: Apatity, St. Petersburg, Moscow, Syktyvkar, Perm, Yekaterinburg, Chelyabinsk, Ufa, Novosibirsk, Irkutsk, and Kazan. One scientist from Berlin also took part in the conference.

Thirty-four papers presented at the plenary meetings were focused on following problems: (1) evolution of the Riphean biosphere and general chronostratigraphic scale of the Riphean; (2) major geologic events and paleogeodynamic reconstructions of the Riphean in northern Eurasia; (3) specific features of Riphean magmatism; (4) geological history of the Riphean stratotype in the Urals; and (5) Upper Precambrian metallogeny and peculiarities of the hydrocarbon distribution. Additionally, over 20 poster presentations devoted to the listed issues took place during the conference.

Basic features of the Riphean biosphere evolution were considered in presentations by M.A. Semikhatov,

M.E. Raaben, A.F. Veis, V.N. Sergeev [all from the Geological Institute of the Russian Academy of Sciences (GIN RAS), Moscow], A.M. Stanevich [East Siberian Research Institute of Geology, Geophysics and Mineral Resources (EastSibRIGGMR), Irkutsk], and A.B. Kuznetsov with coauthors [Institute of Precambrian Geology and Geochronology of the Russian Academy of Sciences (IPGG RAS), St. Petersburg]. They showed that in comparison to the mid-1940s, when substantiation and subdivision of the Riphean was based only on the historical-geological method, the Upper Precambrian stratigraphy in recent years significantly widened its methodology. Now, biostratigraphic, isotopic-geochronologic, chemostratigraphic, and paleoclimatic methods are widely used; the paleomagnetic method has also become a routine tool in the Riphean research.

V.A. Koroteev with coauthors (IGG UD RAS, Yekaterinburg), N.M. Chumakov (GIN RAS, Moscow), A.S. Varlakov (Institute of Mineralogy of the Ural Division of the Russian Academy of Sciences, Miass), K.S. Ivanov and S.N. Ivanov (IGG UD RAS), Yu.K. Sovetov [United Institute of Geology, Geochemistry and Mineralogy of the Siberian Division of the Russian Academy of Sciences (UIGGM SD RAS), Novosibirsk], and some others analyzed principal geologic and paleoclimatic events, and paleogeodynamics of the Riphean in northern Eurasia. According to V.N. Puchkov [Institute of Geology of the Ufa Research Center of the Russian Academy of Sciences (IG URC RAS), Ufa], the formation of the fold belt along the eastern edge of the Russian platform at the end of the Proterozoic correlates with the Cadomian, but not Baikalian phase. The presentation by K.S. Ivanov and S.N. Ivanov focused on some debatable problems of the Riphean tectonics of the Urals. They stressed that studies on the Upper Precambrian geology of the Urals are far from complete, and further progress here may result from the joint efforts of different specialists. N.M. Chumakov showed that it is now possible to reconstruct basic features of the earth's climatic zonation in the Late Riphean and Vendian, and that glacial complexes of ancient epochs were formed as a result of global, relatively short-term (10–20 m.y.) coolings. The latter observation allows these complexes to be used as climatostratigraphic horizons.

During the second day, the conference activity was devoted to the Uralian stratotype of the Riphean and general problems of the Riphean geology of the Urals. V.V. Shalaginov (Joint-Stock Company Ural'skaya geologo-s"emochnaya ekspeditsiya, Yekaterinburg), N.D. Sergeeva with coauthors (IG URC RAS, Ufa), V.P. Parnachev (Tomsk State University, Tomsk), A.V. Maslov, L.V. Anfimov, and M.T. Krupenin (all three from IGG UD RAS, Yekaterinburg), E.Z. Gareev (IG URC RAS, Ufa), and V.I. Petrov (Chelyabinsk Geologic-Geophysical Enterprise, Chelyabinsk) considered crucial problems of stratigraphy, tectonics, paleogeodynamics, sedimentogenesis, and lithogenesis, as well as the geochemistry of sedimentary rocks and metallogeny of the Riphean deposits of the Urals. The presented geologic materials revealed several debatable points. The most important among them concern the paleogeodynamic nature of so-called "riftogenic formations" of the Riphean standard, peculiar features of the Riphean sedimentary basins in the junction zone of the East European platform and western slope of the Urals, and correlation of the type sections of the Bashkirian meganticlinorium with those of the Maksyutov and Suvanyak complexes of the Ural-Tau Range. Despite the traditional correlation of these complexes with the Middle–Upper Riphean–Vendian sequences, they are reported to contain Early Paleozoic fauna (conodonts and other fossils), and this requires a thorough revision of current viewpoints on the age and correlation of the complexes.

Several papers dealt with the peculiar features of the Riphean magmatism. Based on geological and petrochemical data, V.A. Dushin (Ural State Mining Academy, Yekaterinburg) suggested that in the Late Riphean, two subparallel island arcs were formed in the Polar Urals, one above the oceanic-type crust and the other, on the transitional crust. Together with island arcs of adjacent regions, they probably composed the single Taimyr–Polar Urals–Enisei volcanic belt of the Riphean time fringing the Siberian platform in the west and north. M.S. Rapoport with coauthors (Ural Geological Committee, Yekaterinburg) showed that the formation of planetary structure of the Urals-Mongolian mobile belt occurred only in the Late Riphean. Based on the analysis of magmatic and metamorphic events in the pre-Paleozoic history of the Urals, A.A. Alekseev (IG URC RAS, Ufa) believes it possible to consider this region as the tectonotype of the Ripheids.

V.A. Prokin and V.M. Necheukhin (both from IGG UD RAS, Yekaterinburg), R.G. Iblaminov and others (Perm State University, Perm), T.V. Belokon' and others (Kama Research Institute of Potassium and Galite Resources, Perm), and Yu.V. Andreev with coauthors (Bashkirian Research-Industrial Peroleum Institute, Ufa) discussed the problems of metallogeny and peculiarities of the hydrocarbon distribution in the Riphean–Vendian deposits of the eastern Russian platform.

Presentations and accompanying discussion resulted in the agreement of participants on the following. Recent studies on the Riphean biostratigraphy and chemostratigraphy made it possible to establish that changes in taxonomic composition of stromatolites and microfossils, and large scale variations in the initial $^{87}Sr/^{86}Sr$ ratio in carbonate rocks are unique paleontologic and chemostratigraphic features of the successive Riphean intervals, and that isotopic-geochronologic data demonstrate the progressing decrease in their duration. This decrease was probably related to the deccelerating rates of both the Precambrian biota evolution and variations in isotopic-geochemical characteristics of the paleoocean. It is thought that this tendency

reflects the general trend of the evolution of Proterozoic systems in time. The essential point is that the taxonomic diversity and individualization degree of microfossil and stromatolite assemblages, which represent specific features of these intervals, also increase upsection.

Isotopic-geochronologic investigations revealed reliable criteria to evaluate the validity of various (sedimentary, in first turn) geochronometers and the most widely used isotopic systems. They also offered the possibility of correct usage of the isochron U–Pb and Pb–Pb methods for carbonate rock dating, thus widening the methodology of the Riphean isotope geochronology.

The conferences particularly emphasized that peculiar bio- and chemostratigraphic characteristics of three Riphean erathems, together with isotopic-geochronologic and, sometimes, climatostratigraphic data, allow these subdivisions to be recognized and correlated in remote sections. This provides a way to substantiate their paleontologic and chemostratigraphic boundaries.

At the same time, it was stated that certain problems of the Riphean geology and paleontology remain thus far unsolved. Of primary importance among them are the following: (1) significance of some organic-walled microfossil assemblages from central and northern Siberia in rock dating is still debatable; (2) there are different viewpoints on the indications and position of the Middle–Upper Riphean boundary in the Siberian sequences; (3) new isotopic-geochronologic information on Riphean reference sections of Russia and neighboring countries is required to satisfy practical requirements; and (4) conflicting paleogeodynamic reconstructions remain in use.

The participants expressed their anxiety that in recent years, biostratigraphic investigations of the Riphean and Vendian in Russia and adjacent countries were drastically reduced. This was first caused by a lesser number of specialists working on this topic. There was also a deep concern regarding the destruction, due to industrial activity, of unique natural objects (classical exposures of the Riphean and Vendian rocks in the Urals and other regions included), which represent environmental monuments and require protection by the state. The participants of the conference appealed to the environment-protecting and geological organizations of the Uralian and adjacent regions for any kind of support and efforts to recover and preserve unique geological objects of the Riphean.

In the opinion of the conference, further research of Riphean deposits in northern Eurasia should be focused on the following problems: (1) more complete biostratigraphic and isotopic-geochronologic substantiation of the Riphean boundaries (those between its subdivisions included); (2) a broader study on microphytologic and stromatolitic remains in the Riphean reference sections and better understanding of their time-and-space distribution in terms of paleoecology based on essentially wider isotopic-geochronologic information on the Riphean reference sections, especially on age constraints for the Middle–Upper Riphean boundary, and for the upper boundary of the Riphean in the Uralian stratotype, which would meet recent requirements; (3) intensification of chemostratigraphic studies and their application to the correlation of reference sections; (4) reconstruction of genetic, paleogeographic, and facial peculiarities of the formation of Riphean sedimentary, volcanogenic-sedimentary, and volcanogenic rock associations, and deciphering of principal regularities in the development of sedimentary basins; (5) structural and tectonic research of fold-rapture deformations in the Riphean sequences and reconstruction of tectonic regime and environments of the formation of Riphean deposits in the Urals fold belt; Riphean stratigraphy, magmatism, and tectonics in the eastern slope of the Urals; (6) thorough studies on specific features of Riphean magmatism in different zones of northern Eurasia.

It was particularly stressed that deep drilling in the eastern Russian platform and central Kama–Belaya depression through a complete Riphean sequence is crucial to solve basic scientific problems concerning the stratigraphy and history of the Riphean rock complexes, and hydrocarbon genesis and accumulation.

The participants expressed their sincere gratitude to the administration of the Institute of Geology and Geochemistry of the Ural Division of the Russian Academy of Sciences and Ural State Mining Academy for organizing and hosting the conference, and to the Russian Foundation for Basic Research for its financial support of this scientific meeting.

Reviewer M.A. Semikhatov

REFERENCES

Schatsky, N.S., *Ocherki tektoniki Volgo-Ural'skoi neftegazonosnoi oblasti i smezhnoi chasti zapadnogo sklona Yuzhnogo Urala* (Essays on Tectonics of the Volga-Urals Oil- and Gas-bearing Region and Adjacent Western Slope of the Southern Urals), Moscow: Mosk. O-vo Ispyt. Prir., 1945, no. 216.

Sokolov, B.S., Age of the Most Ancient Sedimentary Rocks in the Russian Platform, *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1952, no. 5, pp. 21–30.

Stratigraphy and Geological Correlation, Vol. 4, No. 6, 1996, pp. 628–630.

Author Index to Volume 4, 1996

Akhmet'ev, M.A. and Reshetov, V.Yu., The Eocene–Early Miocene Evolution of Plant Assemblages and Large Mammals in the Extratropical Asia	4	371–377
Alekseev, A.S., Gorbachik, T.N., Smirnova, S.B., and Bragin, N.Yu., Age of the Paramonovo Formation (the Albian of the Russian Platform) and Global Transgressive-Regressive Cycles of the Cretaceous	4	341–361
Alekseeva, R.E., Aristov, V.A., Goryunova, R.V., Ulitina, L.M., and Erlanger, O.A., Emsian and Eifelian Reference Sections of Mongolia	1	51–56
Barskov, I.S. and Reimers, A.N., Carboniferous-Permian Boundary as Indicated by Conodonts	5	428–439
Ben'yamovskii, V.N. and Gladenkov, Yu.B., Paleogene Climatic Fluctuations and Biotic Migrations in the North Pacific	5	480–495
Bidashko, F.G. and Petrenko, Yu.V., Early Holocene Fossil Insects Fauna and Natural Environments in the Ural River Lower Course	5	514–516
Bogolepova, O.K., Cephalopod Limestone Facies of the Silurian: the Taimyr Peninsula and Carnic Alps	3	310–314
Bolikhovskaya, N.S. and Sudakova, N.G., The Chekalin (Likhvin) Reference Section in the Russian Plain and Its Significance for Pleistocene Stratigraphy and Correlation	3	294–304
Bragin, N.Yu. and Krylov, K.A., Stratigraphy and Lithology of the Upper Triassic Deposits of Southwestern Cyprus (Vlambouros Formation)	2	132–140
Bragina, L.G. and Bragin, N.Yu., Stratigraphy and Radiolarians from the Type Section of Perapedhi Formation (Upper Cretaceous of Cyprus)	3	246–253
Bubenshchikova, N.V. and Blyum, N.S., Pliocene–Quaternary Biostratigraphy and Planktonic Foraminifera Evolution in the North Pacific	3	277–286
Chumakov, N.M., The School of Thought of Academician V.V. Menner	1	5–13
Devyatkin, E.V., Dodonov, A.E., Gablina, S.S., Golovina, L.A., Kurenkova, V.G., Simakova, A.N., Trubikhin, V.M., Yasamanov, N.A., Khatib, K., and Nseir, H., Upper Pliocene–Lower Pleistocene Marine Deposits of Western Syria: Stratigraphy and Paleogeography	1	67–77
Dorofeeva, L.A., Prilutskii, R.E., and Shkatova, V.K., The Double Carbonate Thermometer as a Tool for Correlation and Stratigraphic Subdivision of the Quaternary Deposits	5	517–522
Dubrovo, I.A., Nigarov, A.N., and Fedorov, P.V., Correlation of Marine and Terrestrial Pliocene–Pleistocene Deposits in the Western Turkmenistan	4	403–408
Fedorov, P.V., The Pontian-Caspian Region as a Possible Stratoregion of the European Pleistocene	6	616–621
Fot'yanova, L.I., Serova, M.Ya., Levin, F.D., and Maslova, N.P., The Paleogene of the Utkholok Peninsula, Western Kamchatka	6	552–566
Gavrilov, Yu.O. and Kopaevich, L.F., Some of the Geochemical, Biochemical, and Biotic Consequences of Eustatic Oscillations	4	315–325
Gladenkov, Yu.B., Vladimir Vasil'evich Menner (On His 90th Birthday)	1	1–4
Gleser, Z.I., Evolutionary Relationship of the Eocene Diatom Flora to Some Abiotic Factors	3	269–276
Gleser, Z.I., Problems of Eocene Siliceous Phytoplankton Zonation (Exemplified by the Caspian Eocene Deposits)	4	392–402
Golovina, L.A., Gablina, S.S., and Simakova, A.N., Paleogeographic Interpretation of Paleoflora from the Pliocene–Pleistocene Sediments of Western Syria	2	202–205
Kemkin, I.V., Tectonics and Stratigraphy of the Perekatnaya–Chernaya Interstream Area, Southern Sikhote-Alin	2	191–201

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Khokhlova, I.E., Paleogene Radiolarians of Southern Russia: Composition and Paleoecological Interpretations 4 362–370

Kholodov, V.N. and Nedumov, R.I., Problems of the Caucasus Paleoland Existence during the Oligocene–Miocene Time 2 181–190

Kirichkova, A.I. and Doludenko, M.P., New Data on the Jurassic Phytostratigraphy in Kazakhstan 5 450–466

Klenina, L.N. and Zaitseva, E.L., Allochthonous Assemblages of Paleozoic Benthic Fossils from the Caspian Syneclise 4 326–340

Klets, T.V., First Discovery of Conodonts from Upper Triassic Deposits of Kotel'nyi Island 6 613–615

Koren, T.N., Biozonal Standards: Calibration Principles, Degree of Sophistication, and Interregional Application (Silurian Graptolites) 6 535–539

Koren', T.N. and Popov, L.E., The Terminal Ordovician Event and Paleozoogeography of Benthic and Planktonic Faunas (Brachiopods and Graptolites) 3 305–309

Koroteev, V.A., Maslov, A.V., and Krupenin, M.T., Fifty Years of Riphean Geology (All-Russian Conference on General Problems of Stratigraphy and Geological History of the Riphean in Northern Eurasia) 6 625–627

Kovach, V.P., Kotov, A.B., Sal'nikova, E.B., Berezkin, V.I., Smelov, A.P., and Zagornaya, N.Yu., Sm-Nd Isotopic Systematics of the Kurumkan Subgroup, the Iengra Group of Aldan Shield 3 213–219

Kovalenko, V.I., Pukhtel, I.S., Yarmolyuk, V.V., Zhuravlev, D.Z., Stosch, H., and Jagoutz, E., The Sm–Nd Isotopic Systematics of Ophiolites in the Ozernaya Zone (Mongolia) 2 107–113

Kuleva, G.V., Yanochkina, Z.A., and Bukina, T.F., Paleoecosystem of *Dorsoplanites panderi* Phase in the Volga Shale-Generating Basin 3 238–245

Leven, E.Ya., The Midian Stage of the Permian and Its Boundaries 6 540–551

Leven, E.Ya., Bogoslovskaya, M.F., Ganelin, V.G., Grunt, T.A., Leonova, T.B., and Reimers, A.N., Reorganization of Marine Biota during the Mid-Early Permian Epoch 1 57–66

Lopatin, A.V., The Stratigraphy and Small Mammals from the Aral Formation, the Altynshokysu Locality, Northern Aral Area 2 166–180

Lopatina, D.A., Pirumova, L.G., and Sorokin, V.M., Diatom Flora from the Upper Quaternary Sediments of the Caspian Sea 1 100–105

Molostovskii, E.A., Some Aspects of Magnetostratigraphic Correlation 3 231–237

Muzylev, N.G., Rasulov, U.M., Khokhlova, I.E., and Kushakov, A.R., The Upper Eocene of the Fergana Depression and Adjacent Regions 2 141–147

Naidin, D.P., Ben'yamovskii, V.N., and Kopaevich, L.F., Paleocene Reference Sections of Mangyshlak 3 254–268

Oreshkina, T.V., Pliocene–Pleistocene Diatoms and Environments in the Northern Tartar Strait 3 287–293

Popov, L.E. and Koren', T.N., Eustatic Events and Black Shale Sedimentation at the Cambrian–Ordovician Boundary 5 419–427

Popov, S.V., Zoogeography of the Late Oligocene Basins of Western Europe Based on Bivalve Mollusks 4 378–391

Povysheva, L.G. and Ustritskii, V.I., Permian Deposits in the Novaya Zemlya Islands 5 440–449

Repin, Yu.S. and Rashwan, N., Chronology and Biochores of Callovian Ammonites from Mangyshlak 5 467–479

Rublev, A.G., State-of-the-Art of the Phanerozoic Isotopic-Geochronologic Scale 6 525–534

Semikhatov, M.A. and Raaben, M.E., Dynamics of the Global Diversity of Proterozoic Stromatolites. Article 2: Africa, Australia, North America, and General Synthesis 1 24–50

Shapiro, M.N., Gladenkov, Yu.B., and Shantser, A.E., Regional Angular Unconformities in the Cenozoic Sequences of Kamchatka 6 567–579

Shcherbinina, E.A. and Kovalenko, D.V., Age of Flysch-Olistostrome Complex in the Eastern Olyutor Range (Southern Koryak Highland) 2 209–211

Shevyrev, A.A., Triassic Stratigraphy of the Northern Caucasus Based on Ammonoids 2 114–131

Shuldiner, V.I., Kozyreva, I.V., and Baltybaev, Sh.K., Geochronology and Formation Subdivisions of the Lower Precambrian in the Northwestern Ladoga Region	3	220–230
Smol'kin, V.F., Skuf'in, P.K., Mitrofanov, F.P., and Mokrousov, V.A., Stratigraphy and Volcanism in the Early Proterozoic Pechenga Structure (Kola Peninsula)	1	78–94
Sudakova, N.G., Gunova, V.S., and Nemtsova, G.M., The Middle–Late Pleistocene Stratigraphy and Paleogeography in Rybinsk–Yaroslavl' Region near the Volga River	2	148–155
Tsekhovskii, Yu.G., Jurassic–Early Cretaceous Landscapes with the Hot Humid Climate in the Northern Arabian Plate	6	606–612
Vangengeim, E.A., Pevzner, M.A., and Tesakov, A.S., Paleogeographic Environments in the Northwestern Regions of the Black Sea Coast in the Early Pliocene	2	206–208
Velichkevich, F.Yu., San'ko, A.F., Rylova, T.B., Nazarov, V.I.†, Khursevich, G.K., and Litvinyuk, G.I., Stratigraphic Scheme of the Quaternary (Anthropogene) Deposits in Belarus	6	594–605
Vislobokova, I.A., Age of the Shand Gol Fauna and Evolution of Central Asia Mammals in the Oligocene	2	156–165
Vitukhin, D.I., Oreshkina, T.V., Pushcharovskii, Yu.M., and Tsukanov, N.V., New Data on the Geology of Iturup Island (Kuril Island Arc)	6	580–593
Volkova, V.S. and Kul'kova, I.A., The Oligocene–Early Miocene Floral Assemblages from Western Siberia	5	496–505
Volozh, Yu.A., Sinel'nikov, A.V., and Groshev, V.G., Stratigraphy of Mesozoic-Cenozoic Deposits in the Salt Dome Basin of the Peri-Caspian Depression	4	409–415
Vorozhbitov, A.M., Conodonts from the Yarovka (Lower Silurian) Horizon of the Altai Mountains	1	95–99
Vyalov, O.S., Il'ina, A.P., and Krymgol'ts, G.Ya., A Chapter in the History of Paleontology and Stratigraphy in Russia	4	416–418
Zhamoida, A.I., Second Edition of the International Stratigraphic Guide	5	506–513
Zhamoida, A.I., Kalacheva, E.D., Prozorovskaya, E.L., Prozorovskii, V.A., Rostovtsev, K.O., and Sei, I.I., Grigorii Yakovlevich Krymgol'ts: On His Ninetieth Birthday	6	622–624
Zhamoida, A.I. and Prozorovskaya, E.L., The Regional, Theoretical and General Stratigraphy as Treated by the Interdepartmental Stratigraphic Committee (ISC)	1	14–23
Awards of NAUKA Publishing Company for Best Publications in 1995	5	523–524

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